IMPROVED PARTICULATE MATERIAL APPLICATION SYSTEM

DESCRIPTION

Related Applications

[Para 1] This application claims the benefit of pending United States provisional patent application serial nos.: 60/524,459 filed on November 24, 2003, for PINCH PUMP WITH VACUUM TUBE; 60/481,602 filed on November 5, 2003, for VIBRATORY SIEVE SCREEN WITH INTEGRAL MOTION GENERATOR; 60/523,012 filed on November 18, 2003 for POWDER SPRAY APPLICATOR; and 60/554,655 filed on March 19, 2004 for POWDER COATING MATERIAL SPRAY GUN; as well as pending International patent application serial no. PCT/US04/26887 filed on August 18, 2004 for SPRAY APPLICATOR FOR PARTICULATE MATERIAL, the entire disclosures all of which are fully incorporated herein by reference.

Technical Field of the Invention

[Para 2] The invention relates generally to material application systems, for example but not limited to powder coating material application systems. More particularly, the invention relates to an applicator that reduces cleaning time, color change time and improves ease of use.

Background of the Invention

[Para 3] Material application systems are used to apply one or more materials in one or more layers to an object. General examples are powder

coating systems, as well as other particulate material application systems such as may be used in the food processing and chemical industries. These are but a few examples of a wide and numerous variety of systems used to apply particulate materials to an object and to which the present invention can find realization.

[Para 4] The application of dry particulate material is especially challenging on a number of different levels. An example, but by no means a limitation on the use and application of the present invention, is the application of powder coating material to objects using a powder spray gun. Because sprayed powder tends to expand into a cloud or diffused spray pattern, known powder application systems use a spray booth for containment. Powder particles that do not adhere to the target object are generally referred to as powder overspray, and these particles tend to fall randomly within the booth and will alight on almost any exposed surface within the spray booth. Therefore, cleaning time and color change times are strongly related to the amount of surface area that is exposed to powder overspray.

[Para 5] In addition to exterior surface areas exposed to powder overspray, color change times and cleaning are strongly related to the amount of interior surface area exposed to the flow of powder during an application process. Examples of such interior surface areas include all surface areas that form the powder flow path, from a supply of the powder all the way through the powder spray gun. The powder flow path typically includes a pump that is used to transfer powder from a powder supply to one or more spray guns. Hoses are commonly used to connect the supply, pumps and guns.

[Para 6] Interior surface areas of the powder flow path are typically cleaned by blowing a purge gas such as pressurized air through portions of the powder flow path. Wear items that have surfaces exposed to material impact, for example a spray nozzle in a typical powder spray gun, can be difficult to clean due to impact fusion of the powder on the wear surfaces.

[Para 7] Most powder spray application systems use a powder containment booth or spray booth in which the objects are sprayed. Powder overspray is

collected by a powder recovery system, which typically operates on the basis of drawing a large volume of air from the spray booth, usually through openings in the walls or floor. This large air volume acts as containment air to prevent powder overspray from falling outside the spray booth. This containment air has entrained powder overspray which is separated from the containment air by a suitable device such as primary filters or cyclones. Since the primary filters or cyclones do not typically extract 100 percent of the entrained powder overspray, after filters are used to filter out residual powder from the air before venting to atmosphere.

[Para 8] Known supply systems for powder coating materials generally involve a container such as a box or hopper that holds a fresh supply of new or 'virgin' powder. This powder is usually fluidized within the hopper, meaning that air is pumped into the powder to produce an almost liquid-like bed of powder. Fluidized powder is typically a rich mixture of material to air. Often, recovered powder overspray is returned to the supply via a sieve arrangement. A venturi pump is used to draw powder through a suction line or tube from the supply into a feed hose and then to push the powder under positive pressure through the hose to a spray gun. Such systems are difficult to clean for a color change operation because the venturi pumps cannot be reverse purged, the suction tubes and associated support frames retain powder and changing the hoppers can be time consuming. The sieve is also challenging and time consuming to clean as it often is in a separate housing structure as part of the powder recovery system or is otherwise not easily accessible. Most of these components need to be cleaned by use of a high pressure air wand which an operator manually uses to blow powder residue back up into a cyclone or other powder recovery unit. Every minute that operators have to spend cleaning and purging the system for color change represents downtime for the system and inefficiency.

[Para 9] There are two generally known types of dry particulate material transfer processes, referred to herein as dilute phase and dense phase. Dilute phase systems utilize a substantial quantity of air to push material through one or more hoses from a supply to a spray applicator. A common pump

design used in powder coating systems is the venturi pump which introduces a large volume of air at higher velocity into the powder flow. In order to achieve adequate powder flow rates (in pounds per minute or pounds per hour for example), the components that make up the flow path must be large enough to accommodate the flow with such a high air to material ratio (in other words lean flow) otherwise significant back pressure and other deleterious effects can occur.

[Para 10] Dense phase systems on the other hand are characterized by a high material to air ratio (in other words rich flow). A dense phase pump is described in pending United States Patent application serial no. 10/501,693 filed on July 16, 2004 for PROCESS AND EQUIPMENT FOR THE CONVEYANCE OF POWDERED MATERIAL, the entire disclosure of which is fully incorporated herein by reference, and which is owned by the assignee of the present invention. This pump is characterized in general by a pump chamber that is partially defined by a gas permeable member. Material, such as powder coating material as an example, is drawn into the chamber at one end by gravity and/or negative pressure and is pushed out of the chamber through an opposite end by positive air pressure. This pump design is very effective for transferring material, in part due to the novel arrangement of a gas permeable member forming part of the pump chamber. The overall pump, however, in some cases may be less than optimal for purging, cleaning, color change, maintenance and material flow rate control.

[Para 11] Many known material application systems utilize electrostatic charging of the particulate material to improve transfer efficiency. One form of electrostatic charging commonly used with powder coating material is corona charging that involves producing an ionized electric field through which the powder passes. The electrostatic field is produced by a high voltage source connected to a charging electrode that is installed in the electrostatic spray gun. Typically these electrodes are disposed directly within the powder path.

Summary of the Invention

[Para 12] The invention provides apparatus and methods for improving the cleanability and reducing color change time for a material application system. Cleanability refers, among other things, to reducing the quantity of powder overspray that needs to be removed from exterior surfaces of the applicator. Cleanability also can refer to reducing the quantity of powder that needs to be purged or otherwise removed from interior surfaces that define the powder path through the spray applicator. Cleanability can also refer to the ease with which the powder flow path can be purged or otherwise cleaned. Improving cleanability results in faster color change times by reducing contamination risk and shortening the amount of time needed to remove a first color powder from the applicator prior to introducing a second color powder.

[Para 13] In accordance with one aspect of the invention, cleanability is improved by reducing the effective exterior surface areas of the spray applicator that are exposed to powder overspray. In accordance with another aspect of the invention, the exterior surfaces are contoured or profiled so as to allow the surface areas to more effectively shed powder overspray. In one embodiment, a spray applicator has a housing that is formed to have a narrow rounded upper portion with steeply sloped sides, as compared to a lower portion of the housing.

[Para 14] In accordance with another aspect of the invention, interior surface areas are reduced so as to reduce the amount of surface area exposed to the flow of material. In accordance with another aspect of the invention, wear surfaces and interior surface areas are reduced by providing a spray applicator that eliminates use of a nozzle device. In one embodiment, the material being applied by the applicator exits the applicator body directly from a feed tube that extends through a housing of the applicator.

[Para 15] In further accordance with this aspect of the invention, interior surface areas are reduced by designing the spray applicator to operate with high density low volume powder feed. In this context, high density means that

the powder fed to the spray applicator has a substantially reduced amount of entrainment or flow air in the powder as compared to conventional powder flow systems. Low volume simply refers to the use of less volume of flow air needed to feed the powder due to its higher density as compared to conventional powder spray guns. By removing a substantial amount of the air in the powder flow, the associated conduits, such as a powder feed hose and a powder feed tube, can be substantially reduced in diameter, thereby substantially reducing the interior surface area. This also results in an significant reduction in the overall size of the spray applicator, thus further reducing the amount of exterior surface area exposed to powder overspray. For manually operated spray applicators, the invention provides an easily replaceable or removable powder path. In any case, a powder flow path is realized that optionally comprises only a single part.

[Para 16] In accordance with another aspect of the invention, a pump and applicator arrangement is contemplated that has a single internal diameter in the powder flow path from the pump outlet to the applicator outlet.

[Para 17] In accordance with another aspect of the invention, a spray applicator is contemplated that operates with high density low volume powder feed. In one embodiment, a spray applicator is provided that includes an air cap positioned at an outlet end of the spray applicator. The air cap permits an air stream to be directed at a high density powder flow that exits a powder feed tube. This arrangement not only eliminates the use of a nozzle, but also adds diffusing or atomizing air into the high density powder stream that exits the feed tube. In an alternative embodiment, an optional exterior electrode is provided in association with the air cap to provide an electrostatic spray applicator. The electrode is disposed exterior the spray applicator housing and powder flow path. In other alternative embodiments, the electrode is retained in an electrode holder that is molded about the electrode, and optionally the electrode holder is keyed to the air cap so that the electrode is always optimally positioned with respect to the outlet end of the powder feed tube.

[Para 18] In accordance with another aspect of the invention, use of the air cap allows for spray pattern control by adjusting the flow of air that impinges on the powder stream. In one embodiment, a switch is provided by which an operator can adjust the spray pattern by simple actuation of the switch while observing the change in pattern shape as more or less air is added to the flow. Software logic is provided to allow for easy adjustment of the spray pattern.

[Para 19] In accordance with another aspect of the invention, spray pattern adjustment is implemented with adjustment of the material flow rate. In one embodiment, when the spray pattern is adjusted by changing the air directed at the powder stream, the material flow rate is adjusted accordingly. The control of pattern shape and flow rates are additional parameters that may be individually or together included in the material application recipes for various objects being processed.

[Para 20] These and other aspects and advantages of the present invention will be apparent to those skilled in the art from the following description of the preferred embodiments in view of the accompanying drawings.

Brief Description of the Drawings

[Para 21] Fig. 1 is a simplified schematic diagram of a powder coating material application system utilizing the present invention;

[Para 22] Fig. 1A illustrates an embodiment of a powder coating material application system of Fig. 1 with the parts of the system as illustrated in the other drawings of the present application;

[Para 23] Fig. 2A is a spray applicator in accordance with the invention and illustrated in longitudinal cross-section;

[Para 24] Fig. 2B is an enlarged view of the forward circled portion of Fig. 2A and Fig. 2C is an enlarged view of the rearward circled portion of Fig. 2A;

[Para 25] Figs. 3A and 3B illustrate the spray applicator of Fig. 2A in exploded perspective;

[Para 26] Fig. 4 is an air cap illustrated in front perspective;

[Para 27] Fig. 5 is a longitudinal section of the air cap of Fig. 4;

[Para 28] Fig. 6 is a longitudinal section of the air cap of Fig. 4 to illustrate an electrode retained therewith;

[Para 29] Figs. 7A-C illustrate an electrode and holder assembly;

[Para 30] Fig. 8A illustrates a manual spray applicator in elevation in accordance with the invention;

[Para 31] Fig. 8B illustrates the applicator of Fig. 8A in longitudinal cross-section;

[Para 32] Fig. 8C is a perspective illustration of a powder tube used in the applicator of Figs. 8A and 8B; and

[Para 33] Fig. 9 is a logic flow diagram for a pattern adjust algorithm in accordance with the invention;

[Para 34] Figs. 10A-10C are assembled and exploded isometric views of a pump in accordance with the invention;

[Para 35] Figs. 10D-10G are elevation and cross-sectional views of the assembled pump of Fig. 10A;

[Para 36] Figs. 11A and 11B are an isometric and upper plan view of a pump manifold;

[Para 37] Figs. 12A and 12B illustrate a first Y-block;

[Para 38] Figs. 13A and 13B are perspective and cross-sectional views of a valve body;

[Para 39] Figs. 14A and 14B illustrate in perspective another Y-block arrangement;

[Para 40] Fig. 15 is an exploded perspective of a supply manifold;

[Para 41] Fig. 16 is an exemplary embodiment of a pneumatic flow arrangement for the pump of Fig. 10A;

[Para 42] Figs. 17A and 17B are an isometric and exploded isometric of a transfer pump in accordance with the invention;

[Para 43] Fig. 18 is an exemplary embodiment of a pneumatic flow arrangement for a transfer pump;

[Para 44] Fig. 19 is an alternative embodiment of a pneumatic circuit for the transfer pump;

[Para 45] Fig. 20 is a representation of material flow rate curves for a pump operating in accordance with the invention; and

[Para 46] Fig. 21 is a graph depicting powder flow rates versus pinch valve open duration for two different pump cycle rates;

[Para 47] Fig. 22 is an isometric illustration of a material supply in accordance with the invention;

[Para 48] Fig. 23 is an exploded isometric of a fluidizing arrangement and support frame;

[Para 49] Fig. 24 is the assembly of Fig. 23 in longitudinal cross-section along the section line 4-4 in Fig. 3;

[Para 50] Fig. 25 is the assembly of Fig. 23 in longitudinal cross-section along the section line 25-25 in Fig. 23;

[Para 51] Fig. 26 illustrates a gasket arrangement for the fluidizing arrangement of Fig. 23, in cross-sectional perspective, enlarged for clarity;

[Para 52] Fig. 27 is a perspective illustration of the material supply in an operational position;

[Para 53] Fig. 27A shows a lance arrangement for drawing powder from a box;

[Para 54] Figs. 28A-28D illustrate a siphon ring in accordance with the invention, wherein Fig. 28A is a perspective from an top view, Fig. 28B is a section taken along the line 28B-28B in Fig. 28C, Fig. 28C is a bottom view and Fig. 28D is an enlarged view of the circled region of Fig. 28B;

[Para 55] Fig. 29 is a cross-sectional illustration of the interface between the siphon ring of Figs. 28A-28D and the fluidizing unit of Figs. 24-26, taken along the line 29-29 in Fig. 22;

[Para 56] Fig. 30 is a perspective of a supply in accordance with the invention installed in a material application system with portions of the system omitted for clarity;

[Para 57] Fig. 31 is another perspective of a supply in accordance with the invention installed in a material application system;

[Para 58] Fig. 32 illustrates a sieve arrangement in accordance with the invention in an operational position;

[Para 59] Fig. 33 illustrates the sieve arrangement of Fig. 32 in a cleaning or color change position;

[Para 60] Fig. 34 illustrates the sieve arrangement of Figs. 32 and 33 in cross-section; and

[Para 61] Fig. 35 illustrates an alternative embodiment for the sieve arrangement.

Detailed Description of the Invention and Exemplary Embodiments Thereof

[Para 62] The invention contemplates a variety of new aspects for a particulate material application system. In general, the invention is directed to three major system functions, namely the supply of material, the applicator used to apply material to an object and a transfer device or pump for transferring powder from the supply to an applicator or from a recovery system to the supply. The three main system functions operationally interface with each other as well as other functions of a typical material application system, including an overspray containment function typically in the form of a spray booth and an overspray recovery function typically in the form of a filter based or cyclone based material recovery devices.

[Para 63] From a system perspective, the invention is directed among other things to improving the cleanability of the system so as to significantly reduce the total time needed for a color change operation. In addition, the invention is directed to various aspects that make the system or subsystems easier to use with less manpower and time involved. In exemplary embodiments of the invention the material is handled in dense phase, but not all aspects of the invention need to be implemented only with dense phase systems. For example but not by way of limitation, many aspects of the invention related to the supply, such as for example the sieving arrangement, can be applied in dilute phase systems.

[Para 64] By "dense phase" is meant that the air present in the particulate flow is about the same as the amount of air used to fluidize the material at the supply such as a feed hopper. As used herein, "dense phase" and "high density" are used to convey the same idea of a low air volume mode of material flow in a pneumatic conveying system where not all of the material particles are carried in suspension. In such a dense phase system, the material is forced along a flow passage by significantly less air volume, with the material flowing more in the nature of plugs that push each other along the passage, somewhat analogous to pushing the plugs as a piston through the passage. With smaller cross-sectional passages this movement can be effected under lower pressures.

[Para 65] In contrast, conventional flow systems tend to use a dilute phase which is a mode of material flow in a pneumatic conveying system where all the particles are carried in suspension. Conventional flow systems introduce a significant quantity of air into the flow stream in order to pump the material from a supply and push it through under positive pressure to the spray application devices. For example, most conventional powder coating spray systems utilize venturi pumps to draw fluidized powder from a supply into the pump. A venturi pump by design adds a significant amount of air to the powder stream. Typically, flow air and atomizing air are added to the powder to push the powder under positive pressure through a feed hose and an applicator device. Thus, in a conventional powder coating spray system, the powder is entrained in a high velocity high volume of air, thus necessitating large diameter powder passageways in order to attain usable powder flow rates.

[Para 66] Dense phase flow is oftentimes used in connection with the transfer of material to a closed vessel under high pressure. The present invention, in being directed to material application rather than simply transport or transfer of material, contemplates flow at substantially lower pressure and flow rates as compared to dense phase transfer under high pressure to a closed vessel.

[Para 67] As compared to conventional dilute phase systems having air volume flow rates of about 3 to about 6 cfm (such as with a venturi pump arrangement, for example), the present invention may operate at about .8 to about 1.6 cfm, for example. Thus, in the present invention, powder delivery rates may be on the order of about 150 to about 300 grams per minute.

[Para 68] Dense phase versus dilute phase flow can also be thought of as rich versus lean concentration of material in the air stream, such that the ratio of material to air is much higher in a dense phase system. In other words, in a dense phase system the same amount of material per unit time is transiting a cross-section (of a tube for example) of lesser area as compared to a dilute phase flow. For example, in some embodiments of the present invention, the cross-sectional area of a powder feed tube is about one-fourth the area of a

feed tube for a conventional venturi type system. For comparable flow of material per unit time then, the material is about four times denser in the air stream as compared to conventional dilute phase systems.

[Para 69] The present invention is directed to a material application system that includes a spray applicator and various improvements therein, some of which are specific to a low pressure dense phase applicator, but others of which will find application in many types of material flow systems, whether dense phase, low pressure dense phase, or other. Accordingly, the present invention is not specifically concerned with the manner in which a dense phase material flow is created and fed to the applicator. In general, dense phase delivery is performed by a pump that operates to pull material into a chamber under negative pressure and discharge the material under positive pressure with a low air volume as noted above. There are a number of known dense phase pump and transfer systems, including but not limited to the following disclosures: EP Application No. 03/014,661.7; PCT Publication 03/024,613 A1; and PCT Publication 03/024,612 A1; the entire disclosures of which are fully incorporated herein by reference.

[Para 70] The invention also contemplates a number of new aspects for a dense phase pump for particulate material. The pump may be used in combination with any number or type of spray applicator devices or spray guns and material supply.

[Para 71] The invention also contemplates a number of new aspects and concepts for a supply that can be used with a particulate material application system. The supply may be used in combination with any number of spray applicator devices or spray guns, spray booths and pumps. The supply is particularly useful with dense phase transport, but may be used with dilute phase transport as well.

[Para 72] With reference to Fig. 1, in an exemplary embodiment, the present invention is illustrated being used with a material application system, such as, for example, a typical powder coating spray system 10. Such an arrangement commonly includes a powder spray booth 12 in which an object or part P is to

be sprayed with a powder coating material. The application of powder to the part P is generally referred to herein as a powder spray, coating or application operation or process, however, there may be any number of control functions, steps and parameters that are controlled and executed before, during and after powder is actually applied to the part.

[Para 73] As is known, the part P is suspended from an overhead conveyor 14 using hangers 16 or any other conveniently suitable arrangements. The booth 12 includes one or more openings 18 through which one or more spray applicators 20 may be used to apply coating material to the part P as it travels through the booth 12. The applicators 20 may be of any number depending on the particular design of the overall system 10. Each applicator can be a manually operated device as in device 20a, or a system controlled device, referred to herein as an automatic applicator 20b, wherein the term “automatic” simply refers to the fact that an automatic applicator is mounted on a support and is triggered on and off by a control system, rather than being manually supported and manually triggered.

[Para 74] It is common in the powder coating material application industry to refer to the powder applicators as powder spray guns, and with respect to the exemplary embodiments herein we will use the terms applicator and gun interchangeably. However, it is intended that the invention is applicable to material application devices other than powder spray guns, and hence the more general term applicator is used to convey the idea that the invention can be used in many material application systems in addition to powder coating material application systems. Some aspects of the invention are applicable to electrostatic spray guns as well as non-electrostatic spray guns. The invention is also not limited by functionality associated with the word “spray”. Although the invention is especially suited to powder spray application, the pump concepts and methods disclosed herein may find use with other material application techniques beyond just spraying, whether such techniques are referred to as dispensing, discharge, application or other terminology that might be used to describe a particular type of material application device.

[Para 75] The spray guns 20 receive powder from a feed center or supply 22 through an associated powder feed or supply hose 24. The terms “feed center” and “supply” are used interchangeably herein to refer to any source of particulate material in accordance with the present invention. To the extent that the supply 22 mimics a feed hopper in the sense of being a container for powder, the supply 22 can be thought of and referred to as a hopper, but, the invention contemplates various design aspects of the supply 22 that are a significant advance over conventional hoppers used to supply powder to a powder spray application system.

[Para 76] The automatic guns 20b typically are mounted on a support 26. The support 26 may be a simple stationary structure, or may be a movable structure, such as an oscillator that can move the guns up and down during a spraying operation, or a gun mover or reciprocator that can move the guns in and out of the spray booth, or a combination thereof.

[Para 77] The spray booth 12 is designed to contain powder overspray within the booth, usually by a large flow of containment air into the booth. This air flow into the booth is usually effected by a powder overspray reclamation or recovery system 28. The recovery system 28 pulls air with entrained powder overspray from the booth, such as for example through a duct 30. In some systems the powder overspray is returned to the feed center 22 as represented by the return line 32. In other systems the powder overspray is either dumped or otherwise reclaimed in a separate receptacle.

[Para 78] In the exemplary embodiment herein, powder is transferred from the recovery system 28 back to the feed center 22 by a first transfer pump 400. A respective gun pump 402 is used to supply powder from the feed center 22 to one or more associated spray applicator or gun 20. For example, a first pump 402a is used to provide dense phase powder flow to the manual gun 20a and a second pump 402b is used to provide dense phase powder flow to the automatic gun 20b. The design of the gun pumps and transfer pumps may be any conveniently available or suitable design. Dense phase pumps,

such as for example the pump described in the patent application noted hereinabove, or dilute phase pumps may be used.

[Para 79] Each gun pump 402 operates from pressurized gas such as ordinary air supplied to the gun by a pneumatic supply manifold 404. Although each manifold and pump assembly is schematically illustrated in Fig. 1 as being directly joined, it is contemplated that in practice the manifolds 404 will be disposed in a cabinet or other enclosure and directly mounted to the pumps 402 through an opening in a wall of the cabinet. In this manner, the manifolds 404, which may include electrical power such as solenoid valves, are isolated from the spraying environment.

[Para 80] The manifold 404 supplies pressurized air to its associated pump 402 for purposes that will be explained hereinafter. In addition, each manifold 404 includes a pressurized pattern air supply 405 that is provided to the spray guns 20 via air hoses or lines 406. Main air 408 is provided to the manifold 404 from any convenient source within the manufacturing facility of the end user of the system 10.

[Para 81] In this embodiment, a second transfer pump 410 is used to transfer powder from a supply 412 of virgin powder (that is to say, unused) to the feed center 22. Those skilled in the art will understand that the number of required transfer pumps 410 and gun pumps 402 will be determined by the requirements of the overall system 10 as well as the spraying operations to be performed using the system 10.

[Para 82] Other than the supply 22, the guns 20 and the pumps 400, 402, the selected design and operation of the material application system 10, including the spray booth 12, the gun mover 26, the conveyor 14, and the recovery system 28, form no required part of the present invention and may be selected based on the requirements of a particular coating application. A control system 34 likewise may be a conventional control system architecture such as a programmable processor based system or other suitable control circuit. The control system 34 executes a wide variety of control functions and algorithms, typically through the use of programmable logic and program

routines, which are generally indicated in Fig. 1 as including but not necessarily limited to feed center control 36 (for example supply controls and pump operation controls), gun operation control 38, gun position control 40 (such as for example control functions for the reciprocator/gun mover 26 when used), powder recovery system control 42 (for example, control functions for cyclone separators, after filter blowers and so on), conveyor control 44 and material application parameter controls 46 (such as for example, powder flow rates, applied film thickness, electrostatic or non-electrostatic application and so on). Conventional control system theory, design and programming may be utilized.

[Para 83] The control functions for gun operation 38 include but are not limited to gun trigger on and off times, electrostatic parameters such as voltage and current settings and monitoring, and powder and air flow rates to the guns. These functions and parameters make up what is commonly known as part recipes, meaning that each part may have its own set of parameters and control functions for each color or type of powder applied. These control functions and parameters may be conventional as is well known. However, in addition, the present invention does contemplate new control functions for the spray applicators and pumps of the present invention, specifically related to spray pattern adjusting and powder atomization air, as will be set forth herein below. This additional gun control function is made available by the present invention in the use of an air assist feature along with the feature of no longer using a nozzle device, used for dense phase powder flow, as contrasted to conventional systems wherein nozzles are commonly used and dense phase powder flow is not used. Still further, the present invention contemplates an optional feature of the pump control, wherein material flow rate is adjusted in response to changes in the spray pattern. These new control features may be incorporated into the overall part recipes.

[Para 84] While the described embodiments herein are presented in the context of a dense phase transport system for use in a powder coating material application system, those skilled in the art will readily appreciate that the present invention may be used in many different dry particulate material

application systems, including but not limited in any manner to: talc on tires, super-absorbents such as for diapers, food related material such as flour, sugar, salt and so on, desiccants, release agents, and pharmaceuticals. These examples are intended to illustrate but not limit the broad application of the invention for dense phase application of particulate material to objects. The specific design and operation of the material application system selected provides no limitation on the present invention unless and except as otherwise expressly noted herein.

[Para 85] While various aspects of the invention are described and illustrated herein as embodied in combination in the exemplary embodiments, these various aspects may be realized in many alternative embodiments, either individually or in various combinations and sub-combinations thereof. Unless expressly excluded herein all such combinations and sun-combinations are intended to be within the scope of the present invention. Still further, while various alternative embodiments as to the various aspects and features of the invention, such as alternative materials, structures, configurations, methods, devices, software, hardware, control logic and so on may be described herein, such descriptions are not intended to be a complete or exhaustive list of available alternative embodiments, whether presently known or later developed. Those skilled in the art may readily adopt one or more of the aspects, concepts or features of the invention into additional embodiments within the scope of the present invention even if such embodiments are not expressly disclosed herein. Additionally, even though some features, concepts or aspects of the invention may be described herein as being a preferred arrangement or method, such description is not intended to suggest that such feature is required or necessary unless expressly so stated. Still further, exemplary or representative values and ranges may be included to assist in understanding the present invention however, such values and ranges are not to be construed in a limiting sense and are intended to be critical values or ranges only if so expressly stated.

[Para 86] Even from the general schematic illustration of Fig. 1 it can be appreciated that such complex systems can be very difficult and time

consuming to clean and to provide for color change. Typical powder coating material is very fine and tends to be applied in a fine cloud or spray pattern directed at the objects being sprayed. Even with the use of electrostatic technology, a significant amount of powder overspray is inevitable. Cross contamination during color change is a significant issue in many industries, therefore it is important that the material application system be able to be thoroughly cleaned between color changes. Color changes however necessitate taking the material application system offline and thus is a cost driver. The present invention is directed to providing a supply that is easier and faster to clean, and thus easier and faster to clean for a color change process. Additional features and aspects of the invention are advantageous separate and apart from the concern for cleanability and color change.

[Para 87] Fig. 1A illustrates an embodiment of a material application system of Fig. 1, with details of the parts of the system being as set forth in the remaining drawings herein along with the accompanying detailed description associated with each figure.

[Para 88] With reference to Figs. 2A and 2B, an exemplary embodiment of an automatic spray applicator 20b in accordance with the invention is illustrated. The same embodiment is illustrated in exploded perspective in Figs. 3A and 3B.

[Para 89] The spray applicator 20b includes a main housing 100 that encloses most of the applicator components. The housing 100 has a powder inlet end 102 and an outlet end 104. A powder tube 106 extends substantially through the housing 100. The powder tube 106 forms a straight and uninterrupted powder path from an inlet end 106a thereof to an outlet end 106b thereof. The powder tube is preferably a single piece of tubing to minimize joints that can trap powder. This makes the applicator 20b easy to clean and purge internally. The only joint in the powder path within the gun housing 100 is where a powder hose (not shown) is connected to the inlet end 102 of the gun as will be described herein below.

[Para 90] In accordance with one aspect of the invention, the gun 20 design is particularly advantageous for cleaning and color change by virtue of being fully operable with a straight through powder tube 106 that extends from the inlet all the way through to the outlet. The tube has a reduced diameter as a result of the dense phase powder flow from the pumps 402 and therefore presents less internal surface area to clean. Moreover, the powder hose that is connected between the gun powder inlet and the pump outlet can be the same diameter as the powder tube diameter. Thus there is a continuous, uniform geometry in the form of a single diameter powder flow path from the pump to the gun outlet. This feature eliminates potential entrapment areas and minimizes resistance to flow. Moreover, the powder flow path is much easier and effective to purge for color change. In accordance with other aspects of the invention as will be set forth hereinbelow, the pumps 402 can be purged in two directions, including forward through the powder hose and through the powder tube. This purging works hand in hand and is facilitated by the uniform geometry of the powder flow path between the pump and gun.

[Para 91] The housing 100 in this embodiment is a three section housing including a front section 100a, an elongated middle section 100b and a back section 100c. The front section 100a includes a boss 108 at its back end that fits inside the forward end of the middle section 100b with preferably a snug friction fit. The back section 100c includes a boss 110 at its forward end that fits inside the rearward end of the middle section 100b with preferably a snug friction fit. The powder tube 106 includes a forward threaded portion 112 that threadably mates with an internally threaded portion of the front section 100a. The powder tube 106 also includes a rearward threaded portion 114 (Fig. 2C) that threadably mates with a lock nut 116. The lock nut 116 partially extends into a counterbore 118 of a heat sink 120. The lock nut 116 abuts the counterbore during assembly of the gun. Once the powder tube 106 has been threadably joined to the front section 100a of the housing 100 and tightened down, the lock nut 116 is then tightened, which causes the powder tube 106 to be pulled backward in tension. This action pulls the three housing sections 100a, b and c axially together in compression such that the powder tube 106

acts like a tie rod to hold the housing sections tightly together. The lock nut 116 includes a seal 122, such as for example an o-ring, that provides a friction fit between the lock nut 116 and the heat sink 120.

[Para 92] A powder tube lock knob 124 is threadably joined to the lock nut 116. A forward end of a powder feed hose 125 is inserted through a bore 126 of the lock knob and bottoms against an inner shoulder 128 formed in the powder tube 106. A lock ring 130 is captured between a forward end of the lock knob 124 and the back edge of the powder tube 106. The lock ring allows easy insertion of a powder feed tube 125 into the inlet end of the gun 20b. The lock ring 130 however grips the outer wall of the feed tube and prevents the feed tube from backing out. The lock ring 130 tightly engages the feed tube 125 when the lock knob 124 is tightened down against the lock nut 116. The powder tube 125 can be easily removed for color change by simply loosening the lock knob 124. A seal 132 is provided to prevent loss of powder. The seal 132 also provides a friction fit so that when the powder tube 125 is removed from the gun, the lock knob 124 does not slide down the length of the powder tube.

[Para 93] It will thus be apparent from Figs. 2A and 2C that the powder path through the spray applicator 20b is defined by the powder tube 116. The only joint is the location 134 where the powder feed hose 125 abuts the powder tube 116 shoulder 128. Other than that one joint, powder can flow along an uninterrupted path through the spray gun to the outlet end 104. Thus the gun is easy to purge for color change and has no significant entrapment areas in the powder path. For use with a dense phase particulate material, the powder tube diameter is substantially reduced as compared to a conventional powder spray gun powder tube. For example, in one embodiment of the invention, the inner diameter of the powder tube may be about six millimeters whereas in a conventional dilute phase system it may be on the order of 11 to 12 millimeters.

[Para 94] The powder tube 106 extends through the housing 100 and the front end 106b is received in a central bore 136 of an air cap 138 that is

retained on the front section 100a by a threaded retaining nut 140. With the powder tube 106 extending all the way through the gun, there is no nozzle device as used in typical prior art powder spray guns. Rather, powder will exit the gun from the front end 106b of the powder tube. The powder tube end 106b may be but need not be aligned generally flush with the forward end of the central bore 136 of the air cap 138.

[Para 95] At this point it is noted that the spray applicator 20b will typically be a rather long device, with most of the length of the applicator defined by the middle section 100b. The overall gun length may be several feet, for example, five feet.

[Para 96] The air cap 138 is best illustrated in Figs. 4 and 5. The air cap 138 is provided in accordance with one aspect of the invention to add air, primarily as atomizing or diffusion air, to the powder flow that exits the powder tube end 106b. The invention contemplates adding air to the powder flow for dense phase particulate systems. In the absence of air being added, the powder flow in a dense phase system is nearly fluid like with the powder flowing much like water in a tube.

[Para 97] The air cap 138 includes a central passage 136 that receives the front end of the powder tube 106. The passage 136 is sized so as to loosely receive the powder tube end. This helps to center the powder stream for proper presentation of the powder stream to the air jets 150. This also allows air to pass around the outside of the tube end to prevent powder from migrating back inside the gun housing. The central passage 136 is defined by a male threaded inner tubular portion 142. The male threads 144 receive a conductive diffuser ring as will be described herein shortly. An outer wall 146 of the air cap is also male threaded as at 148 and mates with the threaded retainer nut 140. The retainer nut 140 is thus threadably joined to the air cap 138 and a threaded end of the front housing section 100a (Fig. 2B) to securely hold the air cap on the housing.

[Para 98] As best illustrated in Fig. 5, the air cap includes two air jet prongs 148a and 148b. Each prong 148 includes one or more air jets 150. The air

jets 150 open into an atomizing or diffusing region 152 that is just forward of the powder tube end 106b. The number of air jets and the angle that their direct air at the powder flow is a matter of design choice to optimize atomization of the powder and to shape the spray pattern as desired. Typically, the more air that is directed at the powder flow will tend to atomize the flow more and enlarge the spray pattern.

[Para 99] The air jets 150 open to an annular air passage 154. The annular air passage 154 further communicates with an annular cavity 156. The annular cavity 156 receives a female threaded air diffuser ring 158 (Fig. 6). The ring 158 is threaded into the air cap 138 with the internal threads 144. As best illustrated in Fig. 3A, the ring 158 includes a plurality if air holes 161 that provide an even air flow within the air cap 138. The ring 158 is also made of a electrically conductive material. For example, the ring 158 may be formed from carbon filled Teflon™. The ring 158 is made conductive because in addition to providing a diffused flow of air through the air cap 138, the ring 158 also electrically connects an electrode assembly 160 to a high voltage multiplier 162.

[Para 100] With reference to Figs. 7A-C and Fig, 6, in accordance with another aspect of the invention an external electrode is provided just downstream from where the powder exits the powder feed tube end 106b. By placing the electrode on the outside of the gun housing 100, it does not interfere with the powder flow or with the cleanability of the powder tube. This is particularly useful with dense phase material flow.

[Para 101] In one embodiment, an electrode assembly 160 is provided that includes an electrode conductor 164 and an electrode holder 166. Preferably although not necessarily the holder 166 is molded over the conductor 164. A short portion 164a of the conductor extends out of the holder 166 and a longer portion 164b extends from the opposite end of the holder 166. The holder 166 is formed with an alignment key 168 in the form of a U-shaped boss that is received in a conforming recess 170 formed in the air cap 138 (see Figs. 4 and 6). In this manner, the electrode holder 166 can only be installed

with one orientation, so that the electrode tip 164a is optimally positioned downstream from the powder tube end 106b. The holder has an extended portion 166b that is inserted into a bore 172 in the air cap 138. A forward portion 166a of the holder 166 positions the electrode tip and is formed at about a right angle to the extended portion 166b.

[Para 102] As best illustrated in Figs. 4 and 6, the inner portion 164b of the electrode is bent down and is captured between the conductive ring 158 and a shoulder 174 in the air cap. In this way, a solid electrical connection is made between the electrode conductor 164 and the conductive ring 158.

[Para 103] With reference to Figs. 2A and 2B, a contact pin 180 is positioned in the front section 100a for intimate contact with a back side of the conductive ring 158. The contact pin 180 is also in contact with a resistor cable 182 which extends back through a forward portion of the middle housing section 100b. The resistor cable 182 may be any conventional resistive assembly that uses resistive carbon fiber and that provides current limiting protection for the electrostatic gun. This protection is enhanced by placing the resistance closer to the electrode. The resistor cable 182 may be supported in the housing with a guide member 184 and is supported at a back end thereof with a bias spring 186. The spring 186 maintains good electrical contact between the pin 180 and the electrical cable 188. The back end of the spring 186 makes electrical contact with a contact of an electrical cable 188. The electrical cable may be in accordance, for example, with United States Patent Nos. 4,576,827 and 4,739,935 issued to the assignee of the present invention, the entire disclosures of which are fully incorporated herein by reference.

[Para 104] The electrical cable 188 extends back through the extended housing mid-section 100b. The electrical cable 188 at its back end makes electrical contact with an output contact 190 of the multiplier 162. A nut 192 may be used to secure the electrical cable 188 to the multiplier output 190.

[Para 105] Thus, in accordance with another aspect of the invention, the high voltage multiplier 162 is positioned in a rearward section of the gun housing, preferably near where the gun is mounted. In this manner the major weight of

the gun is supported at the back end to significantly reduce the vibration and movement of the forward portion of the gun. If the multiplier were positioned closer to the front of the gun, as in conventional powder guns, the cantilever mounting could cause large bending moments. Thus, the invention contemplates an arrangement of a multiplier in line with an electrical cable coupled to a resistance and the electrode, with the multiplier in a rearward portion of the gun and the resistance positioned near the front of the gun.

[Para 106] The multiplier 162 is mounted to a bracket member 194 by a bolt 196. The bracket is thermally conductive, such as made of aluminum that is also mounted to the heat sink 120 by a pair of screws 198. In this manner the multiplier can be cooled by the heat sink 120. A conventional electrical input connector 121 is used to provide the input drive voltage, typically a low DC voltage, to the multiplier input as is known.

[Para 107] An air tube 200 is pushed onto a nipple 202 formed in the front housing section 100a. The nipple 202 forms an air passage to a main air passage 204 that opens to the annular cavity 156 just behind the conductive ring 158. Air that flows down the air tube 200 thus passes through the holes 161 in the ring 158 and then out the air jets 150 in the air cap 138 as described herein above.

[Para 108] The air tube 200 extends back through the gun housing 100 to a male connector 206. The male connector 206 mates with a first bore 208 that is formed in the front face 210 of the heat sink 120 (see Fig. 2C). The first bore 208 opens to a second bore 212 that is formed in the back face 214 of the heat sink 120. It will be noted from Fig. 2C that the centerline axis of the first bore 208 is offset from the centerline axis of the second bore 212 even though they are in fluid communication. This causes air turbulence and better cooling of the heat sink 120. A second fitting 216 is connected to the second bore 212 and serves as a connection for a main air hose (not shown). By this arrangement, air is thus provided to the air cap at the front of the gun, and the multiplier is cooled by the heat sink that is exposed to the same flow of air that goes to the air cap.

[Para 109] The exploded views of Figs. 3A and 3B are provided to better illustrate the assembly described herein above.

[Para 110] In accordance with another aspect of the invention, as best illustrated in Figs. 3A and 3B, the housing 100 sections are preferably formed with a tapered upper portion 220 formed by two rather steep walls 222 that join at a small radius apex 224. Preferably the apex is the top of the gun housing when the gun is being used for spraying material, so that the profile of the gun housing 100 reduces the amount of powder overspray that can alight on the gun and the steep sides can help shed powder.

[Para 111] With reference to Figs. 8A and 8B, the present invention also contemplates a manual spray applicator 250 that is particularly but not exclusively suited for dense phase material application. Many features of the manual version are the same as the automatic spray applicator described herein above.

[Para 112] The manual gun 250 includes a housing 252 that in this embodiment is a two piece housing including a rear or multiplier section 254 and a front or powder tube section 256 in the form of a barrel. These sections can be releasably secured together by any convenient mechanism such as a set screw for example. There is an air cap 258 that is retained on the outlet end of the front housing 256 by a retainer nut 260. The air cap holds an electrode assembly 262 and also a conductive diffuser ring 263 (shown in Fig. 8B). The air cap includes air jets 259. The air cap 258, retainer nut 260, electrode assembly 262 (including an electrode conductor and over-molded electrode holder) and conductive diffuser ring 263 may be the same design and operation as the corresponding parts in the automatic gun version described herein above.

[Para 113] The manual gun 250 further includes an air inlet, such as a fitting 264 that is connectable to an air line (not shown). An electrical connector 266 is provided for connection with an external low voltage power supply to operate the internal high voltage multiplier 268 (shown in dotted line in Fig. 8). The multiplier 268 is disposed in the rear housing section 254 above the

grip handle 270 to reduce operator fatigue. The powder tube housing may be provided in any length as needed, or alternatively can be connectable to an extension housing if so desired for additional length of the spray applicator 250.

[Para 114] Operation of the manual gun 250 is similar to the automatic version except that the manual gun is manually triggered by an operator. Thus the manual gun includes a control trigger device 271. When this trigger 271 is depressed it causes electrical power to be delivered to the multiplier when electrostatic operation is to be used. Actuation of the control trigger 271 also allows air to flow to the air cap 258 via passages that extend through the handle 270 and the housing 252. Air may also be used to cool the multiplier via a heat sink as in the automatic version. The control trigger 271 actuation also causes powder to flow through the gun from a powder feed hose 273 and out the front end of the gun.

[Para 115] Air enters the applicator 250 via the air fitting 264 and into a passage 272 in the handle 270. This air can be used to help cool the multiplier 268. The passage 272 is in fluid communication with an air passage 274 in the front housing section 256. The passage 274 extends through the front housing section and opens to a recess 276 in the air cap 258 that receives the diffuser ring 263.

[Para 116] The electrode 262 makes electrical contact with the diffuser ring 263 in a manner as described herein above. There is also a contact pin 278 that contacts the ring 263. The contact pin 278 is part of an electrical circuit that includes a spring electrode 280 and a resistor assembly 282 and a conductive electrode spacer 282a that is electrically coupled to an output of the multiplier 268. The electrode spacer 282a may for example be made of a conductive Teflon™ material. This electrical circuit may be similar as described herein above in the embodiment of the automatic gun.

[Para 117] The powder feed hose 273 is inserted into a tubular extension 284 of the front housing section 256. A female threaded tube lock knob 286 and a lock ring 288 may be used to retain the feed hose 273 in the tubular extension

284. The lock ring and lock knob may be designed to function in a manner similar to the corresponding parts in the automatic gun described herein before.

[Para 118] The forward end 273a of the feed hose 273 inserts into a hose passageway 290 formed in a powder tube 292. The passageway 290 opens to a powder passage 294 that preferably lies along the central longitudinal axis of the applicator 250. The distal end 294a of the passageway 294 is formed by a tubular portion 296 of the powder tube 292 (see also Fig. 8C). The powder tube 292 is slip fit or otherwise slideably installed into the front housing section 256 with the passageway 290 aligning with the tubular extension 284 so that the powder feed hose 273 can easily be inserted into the powder tube 292. Note that the distal end 294a is received in the air cap 258 in a manner similar to the feed tube 106 and the air cap 138 in the automatic gun embodiment described herein above. The powder tube 292 thus forms a small diameter passageway for powder flow to the front of the gun, so that the manual gun 250 is well suited, for example, for dense phase powder flow.

[Para 119] The powder tube 292 thus provides an easily removable unit that forms the entire powder flow path for the spray gun 250. This makes the manual gun easy to clean for color change.

[Para 120] In accordance with another aspect of the invention, an adjusting member or control device in the form of a second trigger device 298 is provided. This trigger 298 may be actuated alone or in combination with the control trigger 271. The second trigger 298 is a pattern adjust trigger by which an operator can adjust the flow of air to the air cap 258. By increasing the air flow, the spray pattern is made larger and vice-versa. As shown in Fig. 1, the control system 34 receives a signal from the pattern adjust trigger 298 (such as, for example, a change in impedance when the contacts close) and in response thereto issues a gun air control signal 299 The air control signal 299 can be used to control an air valve (not shown) disposed either inside the gun 250 or preferably in a pneumatic control section of the overall powder

application system 10 to increase or decrease air flow to the air cap jets 259 as required.

[Para 121] With reference to Fig. 9, an exemplary flow diagram is provided for a pattern adjust logic routine or algorithm. At step 300 the logic determines if the gun pattern adjust trigger 298 is activated (a de-bounce subroutine may optionally be included to prevent air adjustment unless the trigger has been activated for a minimum time period.) If it is not, the program waits until a valid trigger signal is received. When the trigger 298 is activated, at step 302 the air flow is incrementally increased. The amount of the incremental increase is a matter of design choice, wherein the operator can be provided with fine adjustment, course adjustment or both. At step 304 the program determines whether maximum air flow is being provided to the spray applicator 250. If it is not, then at step 306 the program checks if the trigger 298 is still on. If it is, the logic loops back to 302 to increment the air flow again. In this manner, the operator can hold the trigger 298 down and watch the pattern change with the increasing air flow, and stop by releasing the trigger 298

[Para 122] At step 306 if the trigger 298 is not still on then the program holds that air flow rate at 308 and loops back to wait for the next trigger actuation at step 300.

[Para 123] If at step 304 the system determines that the maximum air flow is being provided, then at step 310 the logic checks if the trigger 298 is still activated. If it is not the program branches to step 308 and holds the air flow rate (and hence the selected pattern). If at step 310 the trigger is still on, then the program resets the air flow back to the minimum air flow rate at 312 and loops back to step 300. Alternatively, at step 312 instead of resetting to the minimum flow rate and waiting for another trigger, the program could branch to step 302 and start incrementing again. This alternative method would allow the operator to keep the trigger depressed and observe the spray pattern as the air flow was adjusted through the maximum air flow rate and them incremented again from the minimum air flow rate. As still another

alternative, rather than having the operator hold the pattern adjust trigger 298 actuated, the system can be programmed to look for a first actuation and then to stop the adjustment in response to a second actuation of the trigger.

[Para 124] As another alternative to the “ramp” feature that is described previously for the pattern shaping air, the control function may be programmed to incorporate a “hi/lo” feature. This “hi/lo” feature would use discrete actuation of the trigger 298 to switch between a “high” and a “low” pattern shaping air flow setting. During normal spraying, say the operator is using the high setting, which he controls from the manual gun controller, to give a large fan pattern. He then comes to an area where he needs a narrow fan pattern to better coat the part. He can actuate trigger 298 once, and the controller will change the flow of pattern shaping air to a lower setting, which the operator has previously set to a certain value through the manual gun controller. A second actuation of trigger 298 will revert the pattern shaping air flow back to the “high” setting.

[Para 125] It should be noted that varying the spray pattern by adjusting the air flow can also be implemented in the automatic spray applicator described herein above because the adjustment is essentially a software logic control function. In the automatic gun version the control system could be provided with a switch for the operator to activate to increment the air flow rate to the gun.

[Para 126] In accordance with another aspect of the invention, the adjustability of the spray pattern can be implemented with an optional adjustment of the material flow rate from the pump 402. As will be described hereinbelow, a pump in accordance with the invention can operate with controllable material flow rates, even at rather low flow rates. This control is based in part on various timing functions within the pump. As used in combination with the spray gun, the control system 39 may be programmed so that in response to a change in the spray pattern, the material flow rate is also adjusted. For example, if the operator changes the spray pattern from a large pattern to a smaller pattern, it may be desirable to lower the material flow rate. Vice-

versa, if the operator increases the spray pattern size it may be desirable to increase the material flow rate. These complementary adjustments can be incorporated into the part recipes within the control logic of the control system 39. As another alternative, the control system 39 may be programmed to adjust the material flow rate as a percentage of a change in the pattern size. Adjustment of the flow rate can save on powder since less powder can be used for special touch ups or other spray operations in which a smaller pattern is used. Those skilled in the art will readily appreciate that there are many such related adjustments that can be made in accordance with the invention. The invention provides such flexibility, in part, by providing a pump that has a scalable flow rate (to be described herein below) and a spray gun that has a scalable or at least an adjustable air flow to the air cap.

[Para 127] In yet another alternative embodiment, a setup mode can be programmed into the control system 39. During the setup mode, an operator can activate the pattern adjust trigger, and either in the ramping mode or step mode the operator can observe the spray patter as applied to an object. The operator can then assess the optimal spray pattern for the object. The air setting and flow rate settings at this optimal spray pattern can then be recorded for future reference when the same part is sprayed again. This information could also be entered into the part recipe database so that the control system 39 can automatically select the pattern and material flow rates the next time that the system is used to spray that part with a similar coating material.

[Para 128] With reference to Figs. 10A, 10B and 10C there is illustrated an exemplary embodiment of a dense phase pump 402 in accordance with the present invention. Although the pump 402 can be used as a transfer pump as well, it is particularly designed as a gun pump for supplying material to the spray applicators 20. The gun pumps 402 and transfer pumps 400 and 410 share many common design features which will be readily apparent from the detailed descriptions herein.

[Para 129] The pump 402 is preferably although need not be modular in design. The modular construction of the pump 402 is realized with a pump manifold body 414 and a valve body 416. The manifold body 414 houses a pair of pump chambers along with a number of air passages as will be further explained herein. The valve body 416 houses a plurality of valve elements as will also be explained herein. The valves respond to air pressure signals that are communicated into the valve body 416 from the manifold body 414. Although the exemplary embodiments herein illustrate the use of pneumatic pinch valves, those skilled in the are will readily appreciate that various aspects and advantages of the present invention can be realized with the use of other control valve designs other than pneumatic pinch valves.

[Para 130] The upper portion 402a of the pump is adapted for purge air arrangements 418a and 418b, and the lower portion 402b of the pump is adapted for a powder inlet hose connector 420 and a powder outlet hose connector 422. A powder feed hose 24 (Fig. 1) is connected to the inlet connector 420 to supply a flow of powder from a supply such as the feed hopper 22. A powder supply hose 406 (Fig. 1) is used to connect the outlet 422 to a spray applicator whether it be a manual or automatic spray gun positioned up at the spray booth 12. The powder supplied to the pump 402 may, but not necessarily must, be fluidized.

[Para 131] Powder flow into an out of the pump 402 thus occurs on a single end 402b of the pump. This allows a purge function 418 to be provided at the opposite end 402a of the pump thus providing an easier purging operation as will be further explained herein.

[Para 132] If there were only one pump chamber (which is a useable embodiment of the invention) then the valve body 416 could be directly connected to the manifold because there would only be the need for two powder paths through the pump. However, in order to produce a steady, consistent and adjustable flow of powder from the pump, two or more pump chambers are provided. When two pump chambers are used, they are preferably operated out of phase so that as one chamber is receiving powder

from the inlet the other is supplying powder to the outlet. In this way, powder flows substantially continuously from the pump. With a single chamber this would not be the case because there is a gap in the powder flow from each individual pump chamber due to the need to first fill the pump chamber with powder. When more than two chambers are used, their timing can be adjusted as needed. In any case it is preferred though not required that all pump chambers communicate with a single inlet and a single outlet.

[Para 133] In accordance with one aspect of the present invention, material flow into and out of each of the pump chambers is accomplished at a single end of the chamber. This provides an arrangement by which a straight through purge function can be used at an opposite end of the pump chamber. Since each pump chamber communicates with the same pump inlet and outlet in the exemplary embodiment, additional modular units are used to provide branched powder flow paths in the form of Y blocks.

[Para 134] A first Y-block 424 is interconnected between the manifold body 414 and the valve body 416. A second Y-block 426 forms the inlet/outlet end of the pump and is connected to the side of the valve body 416 that is opposite the first Y-block 424. A first set of bolts 428 are used to join the manifold body 414, first Y-block 424 and the valve body 416 together. A second set of bolts 430 are used to join the second Y-block 426 to the valve body 416. Thus the pump in Fig. 10A when fully assembled is very compact and sturdy, yet the lower Y-block 426 can easily and separately be removed for replacement of flow path wear parts without complete disassembly of the pump. The first Y-block 424 provides a two branch powder flow path away from each powder chamber. One branch from each chamber communicates with the pump inlet 420 through the valve body 416 and the other branch from each chamber communicates with the pump outlet 422 through the valve body 416. The second Y-block 426 is used to combine the common powder flow paths from the valve body 416 to the inlet 420 and outlet 422 of the pump. In this manner, each pump chamber communicates with the pump inlet through a control valve and with the pump outlet through another control

valve. Thus, in the exemplary embodiment, there are four control valves in the valve body that control flow of powder into and out of the pump chambers.

[Para 135] The manifold body 414 is shown in detail in Figs. 10B, 10E, 10G, 11A and 11B. The manifold 414 includes a body 432 having first and second bores therethrough 434, 436 respectively. Each of the bores receives a generally cylindrical gas permeable filter member 438 and 440 respectively. The gas permeable filter members 438, 440 include lower reduced outside diameter ends 438a and 440a which insert into a counterbore inside the first Y-block 424 (Fig. 12B) which helps to maintain the members 438, 440 aligned and stable. The upper ends of the filter members abut the bottom ends of purge air fittings 504 with appropriate seals as required. The filter members 438, 440 each define an interior volume (438c, 440c) that serves as a powder pump chamber so that there are two pump powder chambers provided in this embodiment. A portion of the bores 434, 436 are adapted to receive the purge air arrangements 418a and 418b as will be described hereinafter.

[Para 136] The filter members 438, 440 may be identical and allow a gas, such as ordinary air, to pass through the cylindrical wall of the member but not powder. The filter members 438, 440 may be made of porous polyethylene, for example. This material is commonly used for fluidizing plates in powder feed hoppers. An exemplary material has about a forty micron opening size and about a 40-50 percent porosity. Such material is commercially available from Genpore or Poron. Other porous materials may be used as needed. The filter members 438, 440 each have a diameter that is less than the diameter of its associated bore 434, 436 so that a small annular space is provided between the wall of the bore and the wall of the filter member (see Figs. 10E, 10G). This annular space serves as a pneumatic pressure chamber. When a pressure chamber has negative pressure applied to it, powder is drawn up into the powder pump chamber and when positive pressure is applied to the pressure chamber the powder in the powder pump chamber is forced out.

[Para 137] The manifold body 432 includes a series of six inlet orifices 442. These orifices 442 are used to input pneumatic energy or signals into the

pump. Four of the orifices 442a, c, d and f are in fluid communication via respective air passages 444a, c, d and f with a respective pressure chamber 446 in the valve block 416 and thus are used to provide valve actuation air as will be explained hereinafter. Note that the air passages 444 extend horizontally from the manifold surface 448 into the manifold body and then extend vertically downward to the bottom surface of the manifold body where they communicate with respective vertical air passages through the upper Y-block 424 and the valve body 416 wherein they join to respective horizontal air passages in the valve body 416 to open into each respective valve pressure chamber. Air filters (not shown) may be included in these air passages to prevent powder from flowing up into the pump manifold 414 and the supply manifold 404 in the event that a valve element or other seal should become compromised. The remaining two orifices, 442b and 442e are respectively in fluid communication with the bores 434, 436 via air passages 444b and 444e. These orifices 442b and 442e are thus used to provide positive and negative pressure to the pump pressure chambers in the manifold body.

[Para 138] The orifices 442 are preferably, although need not be, formed in a single planar surface 448 of the manifold body. The air supply manifold 404 includes a corresponding set of orifices that align with the pump orifices 442 and are in fluid communication therewith when the supply manifold 404 is mounted on the pump manifold 414. In this manner the supply manifold 404 can supply all required pump air for the valves and pump chambers through a simple planar interface. A seal gasket 450 is compressed between the faces of the pump manifold 414 and the supply manifold 404 to provide fluid tight seals between the orifices. Because of the volume, pressure and velocity desired for purge air, preferably separate purge air connections are used between the supply manifold and the pump manifold. Although the planar interface between the two manifolds is preferred it is not required, and individual connections for each pneumatic input to the pump from the supply manifold 404 could be used as required. The planar interface allows for the supply manifold 404, which in some embodiments includes electrical solenoids, to be placed inside a cabinet with the pump on the outside of the

cabinet (mounted to the supply manifold through an opening in a cabinet wall) so as to help isolate electrical energy from the overall system 10. It is noted in passing that the pump 402 need not be mounted in any particular orientation during use.

[Para 139] With reference to Figs. 12A and 12B, the first Y-block 424 includes first and second ports 452, 454 that align with their respective pump chamber 434, 436. Each of the ports 452, 454 communicates with two branches 452a, 452b and 454a, 454b respectively (Fig. 12B only shows the branches for the port 452). Thus, the port 452 communicates with branches 452a and 452b. Therefore, there are a total of four branches in the first Y-block 424 wherein two of the branches communicate with one pressure chamber and the other two communicate with the other pressure chamber. The branches 452a, b and 454a, b form part of the powder path through the pump for the two pump chambers. Flow of powder through each of the four branches is controlled by a separate pinch valve in the valve body 416 as will be described herein. Note that the Y-block 424 also includes four through air passages 456a, c, d, f which are in fluid communication with the air passages 444a, c, d and f respectively in the manifold body 414. A gasket 459 may be used to provide fluid tight connection between the manifold body 414 and the first Y-block 424.

[Para 140] The ports 452 and 454 include counterbores 458, 460 which receive seals 462, 464 (Fig. 10C) such as conventional o-rings. These seals provide a fluid tight seal between the lower ends of the filter members 438, 440 and the Y-block ports 452, 454. They also allow for slight tolerance variations so that the filter members are tightly held in place.

[Para 141] With additional reference to Figs. 13A and 13B, the valve body 416 includes four through bores 446a, 446b, 446c and 446d that function as pressure chambers for a corresponding number of pinch valves. The upper surface 466 of the valve body includes two recessed regions 468 and 470 each of which includes two ports, each port being formed by one end of a respective bore 446. In this embodiment, the first recessed portion 468 includes orifices

472 and 474 which are formed by their respective bores 446b and 446a respectively. Likewise, the second recessed portion 470 includes orifices 476 and 478 which are formed by their respective bores 446d and 446c respectively. Corresponding orifices are formed on the opposite side face 479 of the valve body 416.

[Para 142] Each of the pressure chambers 446a-d retains either an inlet pinch valve element 480 or an outlet pinch valve 481. Each pinch valve element 480, 481 is a fairly soft flexible member made of a suitable material, such as for example, natural rubber, latex or silicone. Each valve element 480, 481 includes a central generally cylindrical body 482 and two flanged ends 484 of a wider diameter than the central body 482. The flanged ends function as seals and are compressed about the bores 446a-d when the valve body 416 is sandwiched between the first Y-block 424 and the second Y-block 426. In this manner, each pinch valve defines a flow path for powder through the valve body 416 to a respective one of the branches 452, 454 in the first Y-block 424. Therefore, one pair of pinch valves (a suction valve and a delivery valve) communicates with one of the pump chambers 440 in the manifold body while the other pair of pinch valves communicates with the other pump chamber 438. There are two pinch valves per chamber because one pinch valve controls the flow of powder into the pump chamber (suction) and the other pinch valve controls the flow of powder out of the pump chamber (delivery). The outer diameter of each pinch valve central body portion 482 is less than the bore diameter of its respect pressure chamber 446. This leaves an annular space surrounding each pinch valve that functions as the pressure chamber for that valve.

[Para 143] The valve body 416 includes air passages 486a-d that communicate respectively with the four pressure chamber bores 446a-d. as illustrated in Fig. 13B. These air passages 486a-d include vertical extensions (as viewed in Fig. 13B) 488a-d. These four air passage extensions 488a, b, c, d respectively are in fluid communication with the vertical portions of the four air passages 444d, f, a, c in the manifold 414 and the vertical passages 456 d, f, a, c in the upper Y-block 424. Seals 490 are provided for air tight connections.

[Para 144] In this manner, each of the pressure chambers 446 in the valve body 416 is in fluid communication with a respective one of the air orifices 442 in the manifold body 414, all through internal passages through the manifold body, the first Y-block and the valve body. When positive air pressure is received from the supply manifold 404 (Fig. 1) into the pump manifold 414, the corresponding valve 480, 481 is closed by the force of the air pressure acting against the outer flexible surface of the flexible valve body. The valves open due to their own resilience and elasticity when external air pressure in the pressure chamber is removed. This true pneumatic actuation avoids any mechanical actuation or other control member being used to open and close the pinch valves which is a significant improvement over the conventional designs. Each of the four pinch valves 480, 481 is preferably separately controlled for the gun pump 402.

[Para 145] In accordance with another aspect of the invention, the valve body 416 is preferably made of a sufficiently transparent material so that an operator can visually observe the opening and closing of the pinch valves therein. A suitable material is acrylic but other transparent materials may be used. The ability to view the pinch valves also gives a good visual indication of a pinch valve failure since powder will be visible.

[Para 146] With additional reference to Figs. 14A and 14B, the remaining part of the pump is the inlet end 402b formed by a second Y-block end body 492. The end body 492 includes first and second recesses 494, 496 each of which is adapted to receive a Y-block 498a and 498b. One of the Y-blocks is used for powder inlet and the other is used for powder outlet. Each Y-block 498 is a wear component due to exposure of its internal surfaces to powder flow. Since the body 492 is simply bolted to the valve body 416, it is a simple matter to replace the wear parts by removing the body 492, thus avoiding having to disassemble the rest of the pump.

[Para 147] Each Y-block 498 includes a lower port 500 that is adapted to receive a fitting or other suitable hose connector 420, 422 (Fig. 10A) with one fitting connected to a hose 24 that runs to a powder supply and another hose

406 to a spray applicator such as a spray gun 20 (Fig. 1). Each Y-block includes two powder path branches 502a, 502b, 502c and 502d that extend away from the port 500. Each powder path in the second Y-blocks 498 are in fluid communication with a respective one of the pinch valves 480, 481 in the pinch valve body 416. Thus, powder that enters the pump at the inlet 420 branches through a first of the two lower Y-blocks 498 into two of the pinch valves and from there to the pump chambers. Likewise powder from the two pump chambers recombine from the other two pinch valves into a single outlet 422 by way of the other lower Y-block 498.

[Para 148] The powder flow paths are as follows. Powder enters through a common inlet 420 and branches via paths 502a or 502b in the lower Y-block 498b to the two inlet or suction pinch valves 480. Each of the inlet pinch valves 480 is connected to a respective one of the powder pump chambers 434, 436 via a respective one branch 452, 454 of a respective path through the first or upper Y-block 424. Each of the other branches 452, 454 of the upper Y-block 424 receive powder from a respective pump chamber, with the powder flowing through the first Y-block 424 to the two outlet or delivery pinch valves 481. Each of the outlet pinch valves 481 is also connected to a respect one of the branches 502 in the lower Y-block 498a wherein the powder from both pump chambers is recombined to the single outlet 422.

[Para 149] The pneumatic flow paths are as follows. When any of the pinch valves is to be closed, the supply manifold 404 issues a pressure increase at the respective orifice 442 in the manifold body 414. The increased air pressure flows through the respective air passage 442, 444 in the manifold body 414, down through the respective air passage 456 in the first Y-block 424 and into the respective air passage 486 in the valve body 416 to the appropriate pressure chamber 446.

[Para 150] It should be noted that a pump in accordance with the present invention provides for a scalable flow rate based on percent fill of the powder pump chambers, meaning that the flow rate of powder from the pump can be accurately controlled by controlling the open time of the pinch valves that feed

powder to the pump chambers. This allows the pump cycle (i.e. the time duration for filling and emptying the pump chambers) to be short enough so that a smooth flow of powder is achieved independent of the flow rate, with the flow rate being separately controlled by operation of the pinch valves. Thus, flow rate can be adjusted entirely by control of the pinch valves without necessarily having to make any physical changes to the pump.

[Para 151] The purge function is greatly simplified in accordance with another aspect of the invention. Because the invention provides a way for powder to enter and exit the pump chambers from a single end, the opposite end of the pump chamber can be used for purge air. With reference to Figs. 10A, 10C, 10E and 10G, a purge air fitting 504 is inserted into the upper end of its respective pump chamber 438, 440. The fittings 504 receive respective check valves 506 that are arranged to only permit flow into the pump chambers 438, 440. The check valves 506 receive respective purge air hose fittings 508 to which a purge air hose can be connected. Purge air is supplied to the pump from the supply manifold 404 as will be described hereinbelow. The purge air thus can flow straight through the powder pump chambers and through the rest of the powder path inside the pump to very effectively purge the pump for a color change operation. No special connections or changes need to be made by the operator to effect this purging operation, thereby reducing cleaning time. Once the system 10 is installed, the purging function is always connected and available, thereby significantly reducing color change time because the purging function can be executed by the control system 39 without the operator having to make or break any powder or pneumatic connections with the pump.

[Para 152] Note from Fig. 1 and 10A that with all four pinch valves 480, 481 in an open condition purge air will flow straight through the pump chambers, through the powder paths in the first Y-block 424, the pinch valves themselves 480, 481, the second Y-block 498 and out both the inlet 420 and the outlet 422. Purge air thus can be supplied throughout the pump and then on to the spray applicator to purge that device as well as to purge the feed hoses back to the powder supply 22. Thus in accordance with the invention, a

dense phase pump concept is provided that allows forward and reverse purging.

[Para 153] With reference to Fig. 15, the supply manifold 404 illustrated is in essence a series of solenoid valves and air sources that control the flow of air to the pump 402. The particular arrangement illustrated in Fig. 15 is exemplary and not intended to be limiting. The supply of air to operate the pump 402 can be done without a manifold arrangement and in a wide variety of ways. The embodiment of Fig. 15 is provided as it is particularly useful for the planar interface arrangement with the pump, however, other manifold designs can also be used.

[Para 154] The supply manifold 404 includes a supply manifold body 510 that has a first planar face 512 that is mounted against the surface 448 of the pump manifold body 414 (Fig. 11A) as previously described herein. Thus the face 512 includes six orifices 514 that align with their respective orifices 442 in the pump manifold 414. The supply manifold body 510 is machined to have the appropriate number and location of air passages therein so that the proper air signals are delivered to the orifices 514 at the correct times. As such, the manifold further includes a series of valves that are used to control the flow of air to the orifices 514 as well as to control the purge air flow. Negative pressure is generated in the manifold 404 by use of a conventional venturi pump 518. System or shop air is provided to the manifold 404 via appropriate fittings 520. The details of the physical manifold arrangement are not necessary to understand and practice the present invention since the manifold simply operates to provide air passages for air sources to operate the pump and can be implemented in a wide variety of ways. Rather, the details of note are described in the context of a schematic diagram of the pneumatic flow. It is noted at this time, however, that in accordance with another aspect of the invention, a separate control valve is provided for each of the pinch valves in the valve body 414 for purposes that will be described hereinafter.

[Para 155] With reference to Fig. 16, a pneumatic diagram is provided for a first embodiment of the invention. Main air 408 enters the supply manifold 404

and goes to a first regulator 532 to provide pump pressure source 534 to the pump chambers 438, 440, as well as pattern shaping air source 405 to the spray applicator 20 via air hose 406. Main air also is used as purge air source 536 under control of a purge air solenoid valve 538. Main air also goes to a second regulator 540 to produce venturi air pressure source 542 used to operate the venturi pump (to produce the negative pressure to the pump chambers 438, 440) and also to produce pinch air source 544 to operate the pinch valves 480, 481.

[Para 156] In accordance with another aspect of the invention, the use of the solenoid control valve 538 or other suitable control device for the purge air provides multiple purge capability. The first aspect is that two or more different purge air pressures and flows can be selected, thus allowing a soft and hard purge function. Other control arrangements besides a solenoid valve can be used to provide two or more purge air flow characteristics. The control system 39 selects soft or hard purge, or a manual input could be used for this selection. For a soft purge function, a lower purge air flow is supplied through the supply manifold 404 into the pump pressure chambers 434, 436 which is the annular space between the porous members 438, 440 and their respective bores 434, 436. The control system 39 further selects one set of pinch valves (suction or delivery) to open while the other set is closed. The purge air bleeds through the porous filters 438, 440 and out the open valves to either purge the system forward to the spray gun 20 or reverse (backward) to the supply 22. The control system 39 then reverses which pinch valves are open and closed. Soft purge may also be done in both directions at the same time by opening all four pinch valves. Similarly, higher purge air pressure and flow may be used for a hard purge function forward, reverse or at the same time. The purge function carried out by bleeding air through the porous members 438, 440 also helps to remove powder that has been trapped by the porous members, thus extending the useful life of the porous members before they need to be replaced.

[Para 157] Hard or system purge can also be effected using the two purge arrangements 418a and 418b. High pressure flow air can be input through the

purge air fittings 508 (the purge air can be provided from the supply manifold 404) and this air flows straight through the powder pump chambers defined in part by the porous members 438, 440 and out the pump. Again, the pinch valves 480, 481 can be selectively operated as desired to purge forward or reverse or at the same time.

[Para 158] It should be noted that the ability to optionally purge in only the forward or reverse direction provides a better purging capability because if purging can only be done in both directions at the same time, the purge air will flow through the path of least resistance whereby some of the powder path regions may not get adequately purged. Fir example, when trying the purge a spray applicator and a supply hopper, if the applicator is completely open to air flow, the purge air will tend to flow out the applicator and might not adequately purge the hopper or supply.

[Para 159] The invention thus provides a pump design by which the entire powder path from the supply to and through the spray guns can be purged separately or at the same time with virtually no operator action required. The optional soft purge may be useful to gently blow out residue powder from the flow path before hitting the powder path with hard purge air, thereby preventing impact fusion or other deleterious effects from a hard purge being performed first.

[Para 160] The positive air pressure 542 for the venturi enters a control solenoid valve 546 and from there goes to the venturi pump 518. The output 518a of the venturi pump is a negative pressure or partial vacuum that is connected to an inlet of two pump solenoid valves 548, 550. The pump valves 548 and 550 are used to control whether positive or negative pressure is applied to the pump chambers 438, 440. Additional inputs of the valves 548, 550 receive positive pressure air from a first servo valve 552 that receives pump pressure air 534. The outlets of the pump valves 548, 550 are connected to a respective one of the pump chambers through the air passage scheme described hereinabove. Note that the purge air 536 is schematically indicated as passing through the porous tubes 438, 440.

[Para 161] Thus, the pump valves 550 and 552 are used to control operation of the pump 402 by alternately applying positive and negative pressure to the pump chambers, typically 180° out of phase so that as one chamber is being pressurized the other is under negative pressure and vice-versa. In this manner, one chamber is filling with powder while the other chamber is emptying. It should be noted that the pump chambers may or may not completely "fill" with powder. As will be explained herein, very low powder flow rates can be accurately controlled using the present invention by use of the independent control valves for the pinch valves. That is, the pinch valves can be independently controlled apart from the cycle rate of the pump chambers to feed more or less powder into the chambers during each pumping cycle.

[Para 162] Pinch valve air 544 is input to four pinch valve control solenoids 554, 556, 558 and 560. Four valves are used so that there is preferably independent timing control of the operation of each of the four pinch valves 480, 481. In Fig. 16, "delivery pinch valve" refers to those two pinch valves 481 through which powder exits the pump chambers and "suction pinch valve" refers to those two pinch valves 480 through which powder is fed to the pump chambers. Though the same reference numeral is used, each suction pinch valve and each delivery pinch valve is separately controlled.

[Para 163] A first delivery solenoid valve 554 controls air pressure to a first delivery pinch valve 481; a second delivery solenoid valve 558 controls air pressure to a second delivery pinch valve 481; a first suction solenoid valve 556 controls air pressure to a first suction pinch valve 480 and a second suction solenoid valve 560 controls air pressure to a second suction pinch valve 480.

[Para 164] The pneumatic diagram of Fig. 16 thus illustrates the functional air flow that the manifold 404 produces in response to various control signals from the control system 39 (Fig. 1).

[Para 165] With reference to Figs. 17A and 17B, and in accordance with another aspect of the invention, a transfer pump 400 is also contemplated. Many

aspects of the transfer pump are the same or similar to the spray applicator pump 402 and therefore need not be repeated in detail.

[Para 166] Although a gun pump 402 may be used as a transfer pump as well, a transfer pump is primarily used for moving larger amounts of powder between receptacles as quickly as needed. Moreover, although a transfer pump as described herein will not have the same four way independent pinch valve operation, a transfer valve may be operated with the same control process as the gun pump. For example, some applications require large amounts of material to be applied over large surfaces yet maintaining control of the finish. A transfer pump could be used as a pump for the applicators by also incorporating the four independent pinch valve control process described herein.

[Para 167] In the system of Fig. 1 a transfer pump 400 is used to move powder from the recovery system 28 (such as a cyclone) back to the feed center 22. A transfer pump 410 is also used to transfer virgin powder from a supply, such as a box, to the feed center 22. In such examples as well as others, the flow characteristics are not as important in a transfer pump because the powder flow is not being sent to a spray applicator. In accordance then with an aspect of the invention, the gun pump is modified to accommodate the performance expectations for a transfer pump.

[Para 168] In the transfer pump 400, to increase the powder flow rate larger pump chambers are needed. In the embodiment of Figs. 17A and 17B, the pump manifold is now replaced with two extended tubular housings 564 and 566 which enclose lengthened porous tubes 568 and 570. The longer tubes 568, 570 can accommodate a greater amount of powder during each pump cycle. The porous tubes 568, 570 have a slightly smaller diameter than the housings 564, 566 so that an annular space is provided therebetween that serves as a pressure chamber for both positive and negative pressure. Air hose fittings 572 and 574 are provided to connect air hoses that are also connected to a source of positive and negative pressure at a transfer pump air

supply system to be described hereinafter. Since a pump manifold is not being used, the pneumatic energy is individually plumbed into the pump 400.

[Para 169] The air hose fittings 572 and 574 are in fluid communication with the pressure chambers within the respective housings 564 and 566. In this manner, powder is drawn into and pushed out of the powder chambers 568, 570 by negative and positive pressure as in the gun pump design. Also similarly, purge port arrangements 576 and 578 are provided and function the same way as in the gun pump design, including check valves 580, 582.

[Para 170] A valve body 584 is provided that houses four pinch valves 585 which control the flow of powder into and out of the pump chambers 568 and 570 as in the gun pump design. As in the gun pump, the pinch valves are disposed in respective pressure chambers in the valve body 584 such that positive air pressure is used to close a valve and the valves open under their own resilience when the positive pressure is removed. A different pinch valve actuation scheme however is used as will be described shortly. An upper Y-block 586 and a lower Y-block 588 are also provided to provide branched powder flow paths as in the gun pump design. The lower Y-block 588 thus is also in communication with a powder inlet fitting 590 and a powder outlet fitting 592. Thus, powder in from the single inlet flows to both pump chambers 568, 570 through respective pinch valves and the upper Y-block 586, and powder out of the pump chambers 568, 570 flows through respective pinch valves to the single outlet 592. The branched powder flow paths are realized in a manner similar to the gun pump embodiment and need not be repeated herein. The transfer pump may also incorporate replaceable wear parts or inserts in the lower Y-block 588 as in the gun pump.

[Para 171] Again, since a pump manifold is not being used in the transfer pump, separate air inlets 594 and 596 are provided for operation of the pinch valves which are disposed in pressure chambers as in the gun pump design. Only two air inlets are needed even though there are four pinch valves for reasons set forth below. An end cap 598 may be used to hold the housings in alignment and provide a structure for the air fittings and purge fittings.

[Para 172] Because quantity of flow is of greater interest in the transfer pump than quality of the powder flow, individual control of all four pinch valves is not needed although it could alternatively be done. As such, pairs of the pinch valves can be actuated at the same time, coincident with the pump cycle rate. In other words, when the one pump chamber is filling with powder, the other is discharging powder, and respective pairs of the pinch valves are thus open and closed. The pinch valves can be actuated synchronously with actuation of positive and negative pressure to the pump chambers. Moreover, single air inlets to the pinch valve pressure chambers can be used by internally connecting respective pairs of the pressure chambers for the pinch valve pairs that operate together. Thus, two pinch valves are used as delivery valves for powder leaving the pump, and two pinch valves are used as suction valves for powder being drawing into the pump. However, because the pump chambers alternate delivery and suction, during each half cycle there is one suction pinch valve open and one delivery pinch valve open, each connected to different ones of the pump chambers. Therefore, internally the valve body 584 the pressure chamber of one of the suction pinch valves and the pressure chamber for one of the delivery pinch valves are connected together, and the pressure chambers of the other two pinch valves are also connected together. This is done for pinch valve pairs in which each pinch valve is connected to a different pump chamber. The interconnection can be accomplished by simply providing cross-passages within the valve body between the pair of pressure chambers.

[Para 173] With reference to Fig. 18, the pneumatic diagram for the transfer pump 400 is somewhat more simplified than for a pump that is used with a spray applicator. Main air 408 is input to a venturi pump 600 that is used to produce negative pressure for the transfer pump chambers. Main air also is input to a regulator 602 with delivery air being supplied to respective inputs to first and second chamber solenoid valves 604, 606. The chamber valves also receive as an input the negative pressure from the venturi pump 600. The solenoid valves 604, 606 have respective outputs 608, 610 that are in fluid communication with the respective pressure chambers of the transfer pump.

[Para 174] The solenoid valves in this embodiment are air actuated rather than electrically actuated. Thus, air signals 612 and 614 from a pneumatic timer or shuttle valve 616 are used to alternate the valves 604, 606 between positive and negative pressure outputs to the pressure chambers of the pump. An example of a suitable pneumatic timer or shuttle valve is model S9 568/68-1/4-SO available from Hoerbiger-Origa. As in the gun pump, the pump chambers alternate such that as one is filling the other is discharging. The shuttle timer signal 612 is also used to actuate a 4-way valve 618. Main air is reduced to a lower pressure by a regulator 620 to produce pinch air 622 for the transfer pump pinch valves. The pinch air 622 is delivered to the 4-way valve 618. The pinch air is coupled to the pinch valves 624 for the one pump chamber and 626 for the other pump chamber such that associated pairs are open and closed together during the same cycle times as the pump chambers. For example, when the delivery pinch valve 624a is open to the one pump chamber, the delivery pinch valve 626a for the other pump chamber is closed, while the suction pinch valve 624b is closed and the suction pinch valve 626b is open. The valves reverse during the second half of each pump cycle so that the pump chambers alternate as with the gun pump. Since the pinch valves operate on the same timing cycle as the pump chambers, a continuous flow of powder is achieved.

[Para 175] Fig. 19 illustrates an alternative embodiment of the transfer pump pneumatic circuit. In this embodiment, the basic operation of the pump is the same, however, now a single valve 628 is used to alternate positive and negative pressure to the pump chambers. In this case, a pneumatic frequency generator 630 is used. A suitable device is model 81 506 490 available from Crouzet. The generator 630 produces a varying air signal that actuates the chamber 4-way valve 628 and the pinch air 4-way valve 618. As such, the alternating cycles of the pump chambers and the associated pinch valves is accomplished.

[Para 176] Fig. 20 illustrates a flow control aspect of the present invention that is made possible by the independent control of the pinch valves 480, 481. This illustration is for explanation purposes and does not represent actual

measured data, but a typical pump in accordance with the present invention will show a similar performance. The graph plots total flow rate in pounds per hour out of the pump versus pump cycle time. A typical pump cycle time of 400 milliseconds means that each pump chamber is filling or discharging during a 400 msec time window as a result of the application of negative and positive pressure to the pressure chambers that surround the porous members. Thus, each chamber fills and discharges during a total time of 800 msec. Graph A shows a typical response if the pinch valves are operated at the same time intervals as the pump chamber. This produces the maximum powder flow for a given cycle time. Thus, as the cycle time increases the amount of powder flow decreases because the pump is operating slower. Flow rate thus increases as the cycle time decreases because the actual time it takes to fill the pump chambers is much less than the pump cycle time. Thus there is a direct relationship between how fast or slow the pump is running (pump cycle time based on the time duration for applying negative and positive pressure to the pump pressure chambers) and the powder flow rate.

[Para 177] Graph B is significant because it illustrates that the powder flow rate, especially low flow rates, can be controlled and selected by changing the pinch valve cycle time relative to the pump cycle time. For example, by shortening the time that the suction pinch valves stay open, less powder will enter the pump chamber, no matter how long the pump chamber is in suction mode. In Fig. 20, for example, graph A shows that at pump cycle time of 400 msec, a flow rate of about 39 pounds per hour is achieved, as at point X. If the pinch valves however are closed in less than 400 msec time, the flow rated drops to point Y or about 11 pounds per hour, even though the pump cycle time remains at 400 msec. What this assures is a smooth consistent powder flow even at low flow rates. Smoother powder flow is effected by higher pump cycle rates, but as noted above this would also produce higher powder flow rates. So to achieve low powder flow rates but with smooth powder flow, the present invention allows control of the powder flow rate even for faster pump cycle rates, because of the ability to individually control operation of the suction pinch valves, and optionally the delivery pinch valves as well. An

operator can easily change flow rate by simply entering in a desired rate. The control system 39 is programmed so that the desired flow rate is effected by an appropriate adjustment of the pinch valve open times. It is contemplated that the flow rate control is accurate enough that in effect this is an open loop flow rate control scheme, as opposed to a closed loop system that uses a sensor to measure actual flow rates. Empirical data can be collected for given overall system designs to measure flow rates at different pump cycle and pinch valve cycle times. This empirical data is then stored as recipes for material flow rates, meaning that if a particular flow rate is requested the control system will know what pinch valve cycle times will achieve that rate. Control of the flow rate, especially at low flow rates, is more accurate and produces a better, more uniform flow by adjusting the pinch valve open or suction times rather than slowing down the pump cycle times as would have to be done with prior systems. Thus the invention provides a scalable pump by which the flow rate of material from the pump can be, if desired, controlled without changing the pump cycle rate.

[Para 178] Fig. 21 further illustrates the pump control concept of the present invention. Graph A shows flow rate versus pinch valve open duration at a pump cycle rate of 500 msec, and Graph B shows the data for a pump cycle rate of 800 msec. Both graphs are for dual chamber pumps as described herein. First it will be noted that for both graphs, flow rate increases with increasing pinch valve open times. Graph B shows however that the flow rate reaches a maximum above a determinable pinch valve open duration. This is because only so much powder can fill the pump chambers regardless of how long the pinch valves are open. Graph A would show a similar plateau if plotted out for the same pinch valve duration times. Both graphs also illustrate that there is a determinable minimum pinch valve open duration in order to get any powder flow from the pump. This is because the pinch valves must be open long enough for powder to actually be sucked into and pushed out of the pump chambers. Note that in general the faster pump rate of Graph A provides a higher flow rate for a given pinch valve duration.

[Para 179] The data and values and graphs provided herein are intended to be exemplary and non-limiting as they are highly dependent on the actual pump design. The control system 39 is easily programmed to provide variable flow rates by simply having the control system 39 adjust the valve open times for the pinch valves and the suction/pressure times for the pump chambers. These functions are handled by the material flow rate control 672 process.

[Para 180] In an alternative embodiment, the material flow rate from the pump can be controlled by adjusting the time duration that suction is applied to the pump pressure chamber to suck powder into the powder pump chamber. While the overall pump cycle may be kept constant, for example 800 msec, the amount of time that suction is actually applied during the 400 msec fill time can be adjusted so as to control the amount of powder that is drawn into the powder pump chamber. The longer the vacuum is applied, the more powder is pulled into the chamber. This allows control and adjustment of the material flow rate separate from using control of the suction and delivery pinch valves.

[Para 181] Use of the separate pinch valve controls however can augment the material flow rate control of this alternative embodiment. For example, as noted the suction time can be adjusted so as to control the amount of powder sucked into the powder chamber each cycle. By also controlling operation of the pinch valves, the timing of when this suction occurs can also be controlled. Suction will only occur while negative pressure is applied to the pressure chamber, but also only while the suction pinch valve is open. Therefore, at the time that the suction time is finished, the suction pinch valve can be closed and the negative pressure to the pressure chamber can be turned off. This has several benefits. One benefit is that by removing the suction force from the pressure chamber, less pressurized air consumption is needed for the venturi pump that creates the negative pressure. Another benefit is that the suction period can be completely isolated from the delivery period (the delivery period being that time period during which positive pressure is applied to the pressure chamber) so that there is no overlap between suction and delivery. This prevents backflow from occurring between the transition time from suction to delivery of powder in the powder pump chamber. Thus, by using

independent pinch valve control with the use of controlling the suction time, the timing of when suction occurs can be controlled to be, for example, in the middle of the suction portion of the pump cycle to prevent overlap into the delivery cycle when positive pressure is applied. As in the embodiment herein of using the pinch valves to control material flow rate, this alternative embodiment can utilize empirical data or other appropriate analysis to determine the appropriate suction duration times and optional pinch valve operation times to control for the desired flow rates.

[Para 182] Thus, the invention contemplates a scalable material flow rate pump output by which is meant that the operator can select the output flow rate of the pump without having to make any changes to the system other than to input the desired flow rate. This can be done through any convenient interface device such as a keyboard or other suitable mechanism, or the flow rates can be programmed into the control system 39 as part of the recipes for applying material to an object. Such recipes commonly include such things as flow rates, voltages, air flow control, pattern shaping, trigger times and so on.

[Para 183] In accordance with further aspects of the invention, a supply for material to a material application system is contemplated that dramatically improves cleanability and ease of use over conventional hopper and other container type designs, thereby also producing a dramatic improvement in color change time. These improvements derive from several unique combinations, sub-combinations and implementation of various functions that heretofore has been carried out separately in a material application system. These functions include, but are not necessarily limited to, a material container or hopper, a material recovery system, a fluidizing arrangement, a sieving arrangement and a suction interface between the container and one or more pumps. In prior systems, the implementation of these various functions led to various structural features and limitations that made cleaning and color change a rather time consuming and labor intensive undertaking. By implementing a drastic departure from conventional implementation approaches, the present invention provides a supply that is easier and faster to

use and to clean, and can be used with dense phase and dilute phase transport processes.

[Para 184] Thus, in accordance with one aspect of the invention, a material supply is provided that is not a conventional container, such as a fluidizing box or hopper, but rather takes a form that facilitates cleaning the supply by an interface with a rather high volume air flow. The exemplary embodiments of the supply are realized in the form of a duct that can be connected and disconnected from a source of negative pressure, especially negative pressure associated with a high volume of air flow. One opening to the duct is available to the negative pressure source, and optionally another opening to the duct is releasably closed by a fluidizing arrangement. A suction interface is also optionally provided with the supply. Thus, the negative pressure air flow cleans not only the duct but also the fluidizing arrangement and the suction interface. The invention especially contemplates interfacing the supply to an air flow system that establishes containment air flow for the spray booth that originates from a material overspray recovery system such as a cyclone and/or filter recovery system. In the exemplary embodiment herein the supply duct is connectable to a filtered flow of air, in this case an after filter unit. In accordance with further aspects of the invention, the supply can optionally accommodate powder feed from a virgin supply, such as a conventional box, and from a recovery system, or both at the same time. Still further, the supply can optionally accommodate a removable sieving arrangement, also with an optional and integrated vibration function.

[Para 185] With reference to Fig. 22 then, a supply 22 in accordance with the present invention is illustrated without being fully interconnected to other functions of the material application system 10. The supply 22 (as used herein with respect to the invention, the words “supply 22” and “hopper 22” are used interchangeably) includes a main body or duct 700 that defines an interior volume 702 for holding powder coating material that will be applied to objects transported through the spray booth 12 (Fig. 1). In the exemplary embodiment the body 700 is generally cylindrical in form, although a cylinder is not required. A cylindrical form is preferred as it is easier to clean. But

other profiles and shapes, including but not limited to frusto-conical receptacles, may be used as required.

[Para 186] An access door 704 is provided in the main body 700. The access door 704 is hinged and provides access to the interior region 702 of the body 700. This access door can be used by an operator to add powder manually to the system and can also be used for cleaning the interior surfaces of the supply 22. The door 704 also provides access to a sieve mounted within the body 700 as will be described in detail hereinafter. In Fig. 22 the door 704 conforms to the cylindrical shape of the main body 700, but any shaped door can be used. In other drawings herein, for example, a rectangular door can be provided or other shape as required.

[Para 187] In this example, the body 700 is formed by a cylindrical portion of sheet metal in the form of a duct. An upper end 700a of the duct is open and is connectable to duct work associated with a powder recovery system, as will be further described herein. A lower portion 700b of the duct has a siphon ring 706 mounted thereto. The siphon ring 706 sealingly engages a fluidizing unit 708 and functions as a suction interface between the supply 22 and the pumps 400, 402 and 410. The fluidizing unit 708 is mounted on a support frame 710 that has two legs 712. The support frame 710 is mounted to a platen 714 that is secured to a lifting mechanism 716. The lifting mechanism 716 operates to raise and lower the platen 714 and hence the fluidizing unit 708 into and out of sealing contact with the bottom of the siphon ring 706. The design of the lifting mechanism 716 in this example is a scissors-like mechanism, but any suitable arrangement can be used to effect a vertical lifting and lower function of the frame 710 and fluidizing unit 708.

[Para 188] The supply 22 may be disposed within a supporting structure 718 that includes a ceiling 720 that secures the upper end 700a to provide a mounting frame for attachment to additional ductwork as will be described hereinafter. A rear wall 722 serves to partially enclose the structure 718, and a large bay 724 is provided on one side of the structure. The bay 724 can be used to enclose various support components of the spray application system,

including in this example electronics and pneumatic controls associated with the gun and transfer pumps 20. An equalization duct opening 726 is provided in the rear wall 722. When the supply 22 is connected into the overall system, as illustrated in additional drawings herein, a containment air flow is produced through the opening 726 that can be used during a color change operation to prevent powder from escaping the interior of the structure 718. Containment air also flows up into the duct 700 as well as the cyclone during a cleaning operation.

[Para 189] At this point it is noted that the supply 22 has two basic operational modes. The first is referred to herein as the supply mode or hopper mode. In this mode, the supply 22 is arranged such that the duct 700 is substantially disconnected from the material recovery system and is in sealed contact with the fluidizing arrangement 708 (via the siphon ring 706.) The supply 22 thus has a configuration in the supply mode much like a container that holds fluidized powder that is sucked out of the container by operation of the pumps. In the supply mode, the lower opening 726 is in fluid communication with the surrounding atmosphere so that the supply 22 operates generally at ambient pressure. In the exemplary embodiments herein the supply 22, when being used in the supply mode, is isolated from negative pressure by virtue of the upper damper being closed, the lower damper being open to balance pressure across the duct 700, and the presence of the transfer pump 400 between the cyclone output and the supply 22 (the pump 400 thus functioning among other things as an isolation device between the supply 22 and the negative pressure of the cyclone.

[Para 190] The other operational mode of the supply 22 is a cleaning mode or color change mode. In this mode, the supply 22 is arranged such that the duct 700 is in fluid communication with the material recovery system (e.g. the after filter unit) and the siphon ring 706 (which is mounted to the duct 700) is separated from the fluidizing unit 708. This allows air to enter the duct to remove by suction powder that is in the duct and on the siphon ring and fluidizing bed, as well as to facilitate cleaning the suction ports by reverse purging the pumps.

[Para 191] The frame 710 includes an open space between the legs 712. This space is provided so that an operator can position a box of virgin powder coating material (see Fig. 27) onto the platen 714 and under the fluidizing unit 708. This arrangement provides for an easy to reach location for a box of virgin powder coating material, but there is no requirement that the virgin powder supply be positioned immediately with the supply 22, because the transfer pump 410 is used to transfer powder from the box or container to an upper portion of the supply 22 as is later described hereinafter in more detail. But, having the powder box or container near the supply enables the air flow through the opening 726 produced by the powder recovery system to contain powder from the box from flowing outside of the structure 718. This location also allows powder to be dumped from the supply 22 during a color change operation. A separate or different box could also be used as required.

[Para 192] An optional box vibration unit 725 may be mounted on the platen 714. The vibration unit 725 typically includes a support frame 725a and a vibration inducing device 725b as is well known.

[Para 193] With reference to Figs. 23, 24, 25 and 26, the legs 712 of the support frame 710 are attached to a bottom plate 728 of the fluidizing unit 708. The fluidizing unit 708 includes a plenum 730 which includes the lower plate 728 and an upwardly extending ring 732 that is provided with an inwardly extending lip 734. The lip 734 provides an annular surface to which a fluidizing member 736 is attached, such as for example, by bolt arrangements 738. The fluidizing member 736 is made of air permeable material that does not allow the powder material to pass through. The fluidizing member 736 thus may be made of the same material as conventional fluidizing plates, such as for example, partially sintered thermoplastic such as polypropylene available from Porex Technologies. The fluidizing member 736 preferably although not necessarily is a somewhat dish shaped plate having an inwardly and downwardly directed slope towards the center region 736a thereof. This slight taper or slope assists powder to fall towards the central region 736a and maintain a fluidized condition during a cleaning or color change operation.

[Para 194] The fluidizing member 736 includes a peripheral recess portion 740 that receives along its inner edge an annular gasket 742. The gasket 742 is held in place by an adhesive. A retainer ring 744 that secures the fluidizing member 736 to the plenum 730 as by the bolts 738. Preferably the gasket 742 includes a generally flat upper surface 742a that is flush or nearly flush with the upper surfaces of the fluidizing plate 736 and the retainer ring 744. This upper surface of the gasket 742 engages with a seal surface of the siphon ring as will be further described hereinafter. Another annular gasket 746 provides a fluid tight seal between the plenum 730 and the fluidizing member 736. The plenum 730 is thus a air tight box into which pressurized air is introduced through an appropriate fitting (not shown). This pressurized air is forced up through the permeable fluidizing member 736 and fluidizes powder that is present in the interior volume of the siphon ring 706 and lower regions of the cylinder 700.

[Para 195] With the fluidizing unit 730 (which includes the plenum, the fluidizing member and the upper exposed siphon ring gasket) integrally mounted on the support frame 710, the fluidizing unit can be raised and lowered into and out of sealed contact with a lower seal surface of the siphon ring 706, by operation of the vertically moveable platen 714.

[Para 196] A central drain hole 748 is provided in the fluidizing bed member 736. During a color change or cleaning operation fluidized powder will flow down through this hole 748 to a dump valve assembly 750. The dump valve assembly 750 may be any convenient design, and may be manually operated or under control of an actuator member. In this exemplary embodiment, the dump valve assembly 750 includes a drain 752 that extends from the fluidizing member drain hole 748 through the bottom plate 728 of the plenum 730. A face gasket or other suitable seal device 754 is used to seal the plenum and trap around the drain hole 748. The drain 752 prevents powder from getting into the plenum 730 interior. A gasketed valve cap 756 is used to selectively open and close the drain 752. The cap 756 is hinged so that it can open in response to actuation of a lever 758. This actuation lever 758 may be operated by a control actuator 760 such as a linear piston type actuator, or

other suitable mechanism. An access door 762 is provided so that an operator can have manual access to the actuator 760. When the valve cap 756 is pivoted away from the drain 752, fluidized powder will drain into the box or other container B positioned between the support legs 712 of the frame 710. This allows most of the powder that falls onto the fluidizing plate 736 to be dumped to the box just prior to initiating a color change or cleaning process. The dumped powder can be dropped into a virgin powder supply box B (also labeled 410 in the drawings) or any other suitable container below the drain 752 for disposal or removal as needed.

[Para 197] One or more sealed air inlets 764 are provided in the drain 752. These inlets are used as purge ports to initially clear unfluidized powder from the drain 752 by injecting pressurized air into the trap to remove residue powder from the trap during a color change or cleaning process.

[Para 198] Fig. 27 illustrates the supply 22 in an exemplary operational position. A boot 766 covers the lifting mechanism 716 to prevent stray powder from getting into the mechanism and acts as a safety guard. The platen 714 may include the vibration device so as to prevent powder inside the box B from compacting. The transfer pump 410 (see Fig. 1 also) is used to transfer powder from the box B into a new powder inlet 770 provided in an upper region 700a of the duct 700 via a powder hose 774. The pump 768 draws powder from the box B through another powder hose 776 that may be, for example, connected to a lance that is inserted into the box. Fig 27A shows the lance 900 in more detail. The hose 776 would be connected by a coupling member 902 to the lance 900 by O-rings (not shown) or other suitable connectors. Hose 776 and lance 900 would have the same internal diameter. The lance would be inserted into the powder contained within box 412 through the top layer 904 of the powder. Box 412 would be supported by a vibrator 906 to facilitate drawing the powder from the box through the lance 900 and hose 776 into transfer pump 410. During color change, the lance would be inserted through a collar 908 of the lower duct portion 700b. The collar 908 would be capped during our normal operation and only uncapped during the color change process when the lance is inserted into the collar.

During the color change process, the powder coating material on the outside of the lance 900 will be drawn off by the air flow through the duct. Alternatively, powder can be blow off the outside of the lance by an air wand similar to the way the sieve is cleaned as described herein. When the lance is inserted into collar 908 during the color change operation, any powder remaining within the interior of the hose 776 and lance 900 will be purged into the duct.

[Para 199] Although not visible in Fig. 27, a sieve is provided, at the mounting flange 772, between the upper region 700a and a central region 700b of the duct body 700. New powder is pumped above the sieve so as to mix with reclaimed powder as will be described hereinafter. The door 704 however can be used for manually adding virgin powder to the supply 22, which is added below the sieve.

[Para 200] The lifting mechanism 716 is used to securely push the fluidizing unit 708 up against the bottom of the siphon ring, in the position illustrated in Fig. 29. The lifting mechanism 716 maintains the fluidizing unit against the siphon ring when the supply is in the supply mode configuration. Clamps 778 or other suitable devices may be used to tightly hold the siphon ring 706 against the fluidizing unit 708 in the case of a loss of lift pressure.

[Para 201] Fig. 27 further shows a series of pumps 402 which are used to transfer powder from within the siphon ring 706 to associated spray application devices such as spray guns 20 (Fig. 1). The pumps 402 may be conventional in design, and preferably although not necessarily are dense phase pumps. Typically there will be one pump per spray application device. As shown in Fig. 1, each pump has an associated powder hose 24 that connects the pump to an outlet in the siphon ring 706 in the supply 22.

[Para 202] Reclaimed powder can also be introduced into the supply 22. This powder is recovered powder overspray from the spray booth 12 (Fig. 1). In the exemplary embodiment, air entrained powder is drawn into a cyclonic separator 780 that functions as part of the powder overspray recovery system 28 (the cyclone is partially shown in Fig. 27). Separated powder falls through

the cyclone 780 into a pan or bin 830 (see also Fig. 30) where it is transferred by the transfer pump 400 through a first hose 32 to a second or reclaimed powder inlet 782 in the upper region 700a of the supply duct 700 via another hose 784.

[Para 203] In the operational position of Fig. 27, powder is introduced into the duct 700 through any one or combination of the access door 704 (manual addition), the new powder inlet 770 (virgin powder via transfer pump 410) or the second inlet 782 (reclaimed powder via transfer pump 400). When the powder enters the upper region 700a of the supply duct 700, it is sieved before falling to the fluidizing unit 708. The gun pumps 402 draw the powder from the siphon ring 706 and pump it to the spray application devices 20. Conventional level sensors 786 may be provided in the vicinity of the siphon ring 706, for example, to detect when powder needs to be added. The control system 39 (Fig. 1) as part of the feed center control function 36 monitors the level sensors 786 and operates the transfer pumps 400, 410 to add powder as needed to the supply duct 700.

[Para 204] With reference to Figs. 28A-28D and Fig. 29, in accordance with another aspect of the invention, the suction interface and function may also be incorporated into the new supply 22 concept. In the exemplary embodiment, the siphon ring 706 is used to provide a device by which the gun pumps 402 can draw fluidized powder out of the supply 22. Gun pumps, whether dense phase or dilute phase, draw powder from a supply by application of a negative pressure to a hose or tube that connects the pump inlet to the powder source. The siphon ring 706 in the exemplary embodiment thus provides a suction interface between the pumps and the fluidized powder swirling within the duct 700 so that the fluidized powder can be drawn out for spraying. The siphon ring 706 can also be reverse purged to help clean the overall supply, as will be further described hereinafter.

[Para 205] The siphon ring 706 includes an upper generally planar mounting surface 800 formed by a radially inwardly extending flange 802 that extends from a cylindrical outer side wall 804. The flange 802 includes a series of

mounting holes 806 that allow the siphon ring 706 to be bolted or otherwise mounted on a flange extension 700c of the lower duct portion 700b (see Figs. 22 and 29). The siphon ring 706 also is formed with an internal profile or geometry defined by the curved surface 808 about its internal periphery. In the exemplary embodiment the surface 808 is defined by an involute such that there is a constantly changing radius to the surface relative to a reference point. However, an involute profile is not required, and other curved or non-curved surface profiles may be used.

[Para 206] A lowermost portion 808a of the siphon ring sealingly contacts the gasket 742 of the fluidizing unit 708 when the fluidizing unit is raised to the position illustrated in Fig. 29. This position is the configuration of the supply 22 when operated in the supply mode.

[Para 207] In accordance with one aspect of the invention, the fluidizing function is enhanced to improve fluidizing and mixing of the powder coating material. The invention contemplates the use of the fluidizing bed member 736 having a diameter that is greater than the diameter of the duct 700. Air flows from the plenum 730 upward through the porous fluidizing bed. The fluidizing bed produces a diffused flow of air across its entire surface, which ventilates through powder through a decreasing volume presented by the transition between the fluidizing bed and the duct 700. This transition causes a higher air flow velocity, like an updraft, at the outer portion of the fluidizing bed. This outer portion is generally defined by the perimeter portion of the fluidizing bed that is radially greater than the outside diameter of the duct 700. The high air flow velocity updraft in this perimeter region produces a suction effect generally across the surface of the fluidizing bed that draws powder radially outward from a central region to the perimeter region. The powder is drawn upward along the outside portion of the siphon ring and the inside wall of the duct 700b, and by gravity and head pressure within the duct 700 the powder then flows across towards the center region and then back downwardly in the central region of the duct and siphon ring. Thus, a circulating, somewhat like a convective flow pattern, is produced within the lower region of the duct 700 and the siphon ring, as represented by the arrows

810 in Fig. 29. This circulatory flow pattern significantly improves the fluidization and mixing of the powder.

[Para 208] The circulating flow can be realized with generally any transition profile between the fluidizing bed and the duct 700. However, in accordance with another aspect of the invention, by providing the involute or other smooth transition profile to the interior perimeter of the siphon ring, there are no entrapment areas within the fluidizing zone, wherein the fluidizing zone can generally be understood as the volume within the lower portion of the duct 700b and within the volume of the siphon ring wherein air is used to fluidize the powder. The smoothly curved profile of the siphon ring, such as by using an involute for example, presents a single continuous surface having any number of recessed or flush suction ports formed therein (for coupling to pumps) with no entrapment areas within the fluidizing zone. The lack of entrapment areas is further effected by locating the suction ports 814 (Figs. 28B and 28D) near the bottom of the siphon ring, just above the upper surface of the fluidizing bed.

[Para 209] When the fluidizing bed is lowered, such as during a color change operation, an operator can easily blow off or wipe off the siphon ring and duct without any irregular surfaces to clean. Much of the residual powder is sucked up from these surfaces by air flow up through the duct 700 and the equalization duct 832 (the equalization duct 832 acts as an exhaust duct for residue powder when the supply 22 is operating in the cleaning mode). In this mode, with the fluidizing bed lowered, air flow also follows up along the siphon ring inner surface and flows in a laminar manner up the sides of the duct 700 to help clean out the duct 700.

[Para 210] Thus, other curved or non-curved profiles for the siphon ring interior surface 808 may be used, particularly if the interior profile of the duct is not cylindrical. Preferably the surface 808 blends with a smooth transition as at 812 to the interior surface of the duct 700b.

[Para 211] By providing the fluidizing bed member 726 with an enlarged diameter relative to the duct 700, the head of powder in the duct 700 does not

change drastically even if a substantial amount of powder is added to the supply 22, thereby minimizing any adverse impact on flow rate and uniformity of the powder to the applicators.

[Para 212] A series of radial through bores 814 are provided and generally, although not necessarily, are equally spaced about a portion of the siphon ring. Each bore 814 includes a counterbore 816 that serves as a powder suction port and is adapted to receive one end of a pump suction hose 24 and/or an appropriate hose connector (see Figs. 22 and 27). These ports are preferably located near the bottom of the ring 706 so that the material application system can operate with as low a material supply as possible to quicken color change.

[Para 213] With reference to Figs. 30 and 31, the material application system 10 can include a number of components including the spray booth 12, the automatic spray guns 20b mounted on a gun mover 820, and a powder overspray recovery system 28, which in the exemplary embodiments includes a twin cyclone separator 780. The spray guns 20b extend into the spray booth through openings or gun slots 18. The cyclones receive powder entrained air at a cyclone inlet 822 via a recovery duct 824 that is in fluid communication with the booth interior. In this example, overspray powder is drawn into the recovery duct 824 by a large air flow created by an after filter blower system (not shown). These blowers move large amounts of air through an exhaust duct 826 that is in fluid communication with an exhaust outlet 828 from the cyclones 780. The after filters provide final filtering of the cyclone exhaust air. The air drawn through the cyclones pulls powder entrained air from the spray booth into the cyclone inlet where the cyclonic operation separates the powder from the air. The recovered powder falls down into the lower portion of the cyclone to a bin or other receptacle 830 where it is transferred by the transfer pump 400 over to the supply 22 through the powder recovery hose 784 as described herein above.

[Para 214] In accordance with another aspect of the invention, the supply 22 is optionally connectable to a source of negative pressure, preferably

accompanied by high air flow. In the exemplary embodiment, this aspect of the invention is realized by providing a duct that interconnects the supply 22 with the duct work of the powder recovery system. This allows the high air flow from the recovery system, such as the after filter blowers, to help clean powder from the duct 700 (and the supply 22 in general) and associated components. This concept is dramatically different from prior powder supply arrangements in which there was no direct connection like that shown between the supply hopper or box and the recovery system.

[Para 215] In accordance with the invention, an equalization duct 832 is provided between the lower opening 726 near the supply 22 and a banjo housing 834. The banjo 834 is simply a duct that provides a common plenum for the dual stack exhausts (not shown) from the twin cyclones. In a single cyclone system the equalization duct 832 can be simply connected into the duct work of the recovery system at any convenient location, typically downstream from the cyclone exhaust port. A first damper 836 is positioned between the equalization duct 832 and the banjo 834. Another duct 838 connects the duct 700 of the supply 22 to the equalization duct 832. In this manner, the negative pressure of the recovery system 28 can be used to produce a high flow of air through the supply 22, including the duct 700 and the siphon ring during a cleaning and/or color change operations. This is also referred to herein as the supply 22 being used in the cleaning mode.

[Para 216] A second or lower damper 840 is provided in the equalization duct 832 above the opening 726. This damper can be a simple two position damper, namely open and closed positions. The damper 840 is closed when the supply 22 is being cleaned or during color change, and is fully open when the supply 22 is being used in the hopper or supply mode. When closed, the damper 840 isolates the opening 726 from the suction force of the after-filter fan. The lower damper is re-opened during the final step of a color change procedure to clean out the partially enclosed supporting structure 718 so that residual powder can be exhausted through the opening 26 or up the cyclone.

[Para 217] The upper damper 836 is preferably a three position damper for reasons that will be explained hereinafter. In one position, the upper damper is fully closed so as to isolate the duct 700 from the negative pressure of the recovery system. This is the normal damper position during a powder application process for which the supply 22 is being used in the supply mode to supply powder to the pumps 402. It is possible that the damper 836 might not completely isolate the supply 22 from the negative pressure of the recovery system 28. Accordingly, the equalization duct 832 is used to provide a pressure balance across the duct 700 during use of the supply 22 in the supply mode. Thus, in the supply mode the supply 22, and particularly the duct 700 and siphon ring operate generally at ambient atmospheric pressure, meaning the atmospheric pressure of the surrounding environment of the material application system 10. This is accomplished by having the lower damper 840 fully open. The equalization duct 832 also provides additional make up air into the duct 700 for the pumps 402 because the fluidization air may not be enough for the pumps to adequately draw powder out of the siphon ring 706. During the cleaning mode, the equalization duct acts as an exhaust duct between the supply 22 and the recovery systems, namely the after filter unit in this embodiment.

[Para 218] Although the upper damper may typically be fully closed during a material application process (i.e. the supply 22 operating in the supply mode), it is possible to partially open the upper damper 836 during a material application process. The lower damper is also open. Opening the upper damper partially provides just enough air flow up through the duct 700 so that the door 704 can be opened without powder flowing out of the duct 700. With the door open during fluidization and suction of powder within the supply 22, an operator can observe the fluidization as well as operation of the sieve located in the upper portion of the duct 700 (described hereinafter). The upper duct can be opened just enough so that the flow of air up the duct 700 contains powder within the duct without adversely impacting the fluidization and suction functions in the fluidization zone of the supply 22.

[Para 219] When a color change or cleaning process is to be performed, the lower damper 840 is fully closed. The after filter blowers are on thereby drawing substantial air flow through the cyclone and through the duct work associated with the supply 22, as well as the duct work associated with the spray booth. With the upper damper partially opened, the platen 714 is lowered about an inch to separate the fluidizing unit 708 from the siphon ring 706. Then the upper damper is fully opened to allow for a substantial air flow to be drawn up into the siphon ring 705 and the duct 700 through the gap created between the fluidizing unit and the siphon ring. This air flow not only removes residue powder within the duct 700 but also cleans off the fluidizing plate and the interior surfaces of the siphon ring. At the same time, the siphon ring can be reverse purged by forcing air back through the bores 814 into the ring interior and up through the duct 700. The reverse air flow can be effected by a purging operation associated with the pumps 402 for example or by any other suitable technique.

[Para 220] When the initial cleaning has been completed, the platen 714 is fully lowered so that all the siphon ring/gasket 804/742 contact points can be visually inspected and wiped down or blown off as needed. The upper damper 836 is still fully opened so that maximum air continues to flow through the duct 700 and out to the recovery system such as the after filter unit.

[Para 221] Accordingly, a significant advantage of this aspect of the present invention is that the supply 22 is connectable to the recovery system to greatly increase the speed of cleaning and color change yet with a simple arrangement requiring significantly reduced labor. Another advantage is that the supply 22 can be, if so desired, physically distant from the cyclone because there is no need to use the cyclone to capture residue powder cleaned from the system. This greatly increases the flexibility in design and layout of the material application system 10 because the supply 22 can be located at its own convenient location on the shop floor regardless of the location of the cyclone. The cyclones can also be positioned much lower to the shop floor since the box or supply need not be positioned there under.

[Para 222] Figs. 31, 32 and 33 illustrate an embodiment of another aspect of the invention. In accordance with this aspect, a sieving arrangement is contemplated in which the sieve has an integral expandable seal and an integral vibration function. The integrated vibration function produces vibration in the sieve arrangement itself only and not the rest of the supply 22 such as the duct 700.

[Para 223] In the exemplary embodiment, the sieve arrangement 842 is designed to be installed in the duct 700, between the upper portion 700a into which virgin and reclaimed powder is added (as described hereinabove) and the lower portion 700b (see Fig. 27). This location provides adequate volume for powder to be added and sieved prior to falling into the fluidizing zone of the duct 700, wherein the fluidizing zone is generally defined as the volume above the fluidizing plate 736 and generally but not necessarily completely within the siphon ring 706. The sieving function not only provides a more consistent feed of material into the fluidizing zone but also helps to uniformly mix the reclaimed and virgin powder, particularly when the vibration function is added to the sieve.

[Para 224] The sieve arrangement 842 preferably can be manually positioned as illustrated in Figs. 32 and 33, and can be reached by an operator through the access door 704. The access door 704 may be provided with hooks or other suitable devices 844 for holding the sieve arrangement 842 during cleaning. Alternatively the sieve could be provided with a hanging device or one can be optionally installed by the operator each time the sieve is cleaned. During the cleaning mode, substantial air is being drawn into the duct 700 through the door opening 704a, therefore, an operator can use an air wand to blow residue off the sieve and into the duct 700. Note also that with the door 704 open the operator can use a mitt or air wand or other suitable cleaning device or combination thereof to finish cleaning the duct 700 interior during a cleaning or color change process.

[Para 225] The sieve arrangement 842 includes a hollow ring 846 that can be made of any suitable material, including metal, plastic, composite and so on.

The ring 846 supports a sieve screen 848 so that the assembly can be installed inside the duct 700 by resting on compliant support pegs 850. An inflatable/deflatable seal device 852 is provided about the periphery of the sieve screen 848 such as within a groove of a screen frame 848a. An air hose 854 is in fluid communication with the seal 852 and is also connected to a source of air pressure (not shown) outside the duct 700 through an opening in the duct wall. The air lines for the sieve are contained within an umbilical 853. The umbilical 853 can alternatively be used to also enclose an ultrasonic energy source for supplemental vibration energy for the sieve. A valve or other control device (not shown) can be provided to allow an operator to inflate or deflate the seal 852. With the sieve in place up inside the duct 700 and resting on the pegs 850, the operator adds air into the seal 852 to expand it. The seal engages the inside wall of the duct 700. The screen seal 852 has the effect of not only installing the sieve in a fluid tight manner within the duct (so that all powder must pass through the sieve screen 848 and not around its perimeter) but it also is a compliant mount that centers the sieve screen within the duct. The seal 852 also dampens the sieve vibrations from being coupled into the duct 700.

[Para 226] To remove the sieve arrangement for cleaning, the operator simply deflates the seal 852, manually grasps the sieve 842 and hangs it on the door 704 outside of the duct 700 for cleaning. In this embodiment, the umbilical 853' may include a quick disconnect arrangement (not shown) so that the entire sieve arrangement hangs from the door and can be easily cleaned off.

[Para 227] The hollow ring 846 has one or more elements inside, such as for example a ball bearing 856. Pressurized air is also injected into the ring 846 through one or more tangential air jets so as to impart motion to the elements 856 which induces vibration into the ring 846 and sieve screen 848. Air may be provided from a branch of the seal air line 854 or separately provided. The ring 846 thus functions as a race for the ball bearing 856. The motion air is exhausted from the ring 846 through an exhaust line 858 and can be exhausted to atmosphere or other locations in the system 10 that uses a pressurized air source. The ball diameter is slightly less than the inside

diameter of the tube 846 so that air pressure will force the ball to spin around the inside of the ring. Supplemental energy may also be provided for vibrating the sieve. For example, ultrasonic energy may also be used in addition to the motion induced vibration.

[Para 228] Fig. 35 illustrates an alternative embodiment of the sieve arrangement as used with a door that conforms to the cylindrical shape of the duct 700. In this embodiment, a strut 860 is associated with the door 704'. In this embodiment, the sieve arrangement 842' is designed to be hung on the strut 860 when the door is open. The strut swings out with the door and swings back out of the way when the door is closed.

[Para 229] The various features of the supply 10 and associated components provide a fast and simple supply design to clean and for color change. An exemplary color change process will now be described, it being understood that this process can be used for cleaning as well as for color change, and that the particular order of the steps is not necessarily required and that various steps may be optional depending on the overall performance requirements of the material application system.

[Para 230] Presuming that the system 10 has been operational during a powder application process, when the spray applicators and pumps are turned off there may be a significant amount of powder still in the duct 700 and the siphon ring 706. The after filter blowers stay on and the fluidizing air to the fluidizing unit 708 remains on. The upper damper 836 is partially opened and the lower damper 840 is fully closed. The dump valve 756 is opened and much of the powder on the fluidizing plate falls down into the box B. The air being drawn into the duct 700 via the upper damper 836 and the ducts 832, 838 also removes powder from inside the duct 700 and the siphon ring and fluidizing unit. The gun pumps 402 and transfer pumps 400, 410 may optionally be reverse purged so that air blows through the radial ports in the siphon ring to clean the ports and help clean the siphon ring, as well as cleaning out the hoses that connect the gun pumps to the siphon ring and the transfer pumps to the duct 700. Air is also fed into the drain 752 (Fig. 25) to

keep powder from remaining in the trap and also to clean the opening 748 in the fluidizing plate 736. The dump valve 750 is closed and the box can be removed. The platen 714 is then lowered a small amount, for example about one inch, to break the fluid tight seal between the fluidizing unit and the siphon ring. Then the upper damper is fully opened and air is drawn into the duct 700 through this small gap and cleans powder from the siphon ring as well as the fluidizing plate. This air flow also back washes the sieve screen 848 (initial air flow when the upper damper is first partially opened also sucks up powder that had remained on top of the sieve screen).

[Para 231] After an appropriate amount of time, such as for example about 10 seconds or so, the plate 714 is completely lowered. Not all of the after filter air however is pulled through the supply 22. Some of the after filter containment air still is pulled through the cyclone to prevent cyclone contamination into the supply duct 700 or into the partially enclosed supporting structure 718.

[Para 232] The operator opens the access door and can use an air wand, a mitt or other cleaning devices or combinations thereof to finish cleaning any small amount of powder that still may be inside the duct 700, the siphon ring and the fluidizing unit. This powder is easily drawn up into the duct 700 and out to the recovery system due to the large air flow. The operator also removes the sieve by deflating the seal and hangs the assembly on the door (or alternatively the strut) so that the air wand can be used to finish blowing off any residue powder on the sieve arrangement. Also, the sieve seal 852 can be cycled between inflated and deflated states, for example about every three seconds, to further dislodge powder from the seal. This also allows an operator to observe proper operation of the inflatable seal. The sieve then is repositioned up into the duct 700. The operator can then clean down the cyclone as needed and as is well known. After final cleaning is done, the lower damper may be closed and the upper damper partially closed. The platen 714 is raised so that the fluidizing unit re-engages the siphon ring. A new box of material can then be positioned under the fluidizing unit and the system is

then ready to go back online (the upper damper will then be fully closed before starting the next material application process.)

[Para 233] By having the supply 22 connectable into the recovery system, cleaning and color change is much faster and easier because the large air flow can be used as an integral part of the cleaning operation even when the supply 22 is positioned remote from the cyclone. One operator is able to clean the supply and cyclone and provide color change in a matter of minutes with little effort and almost no tools. This arrangement also improves the purging and cleaning of the pumps and associated equipment.

[Para 234] As a still further alternative embodiment, it will be appreciated by those skilled in the art that the supply 22 lower works, including a lower portion of the duct 700, the siphon ring 706, the fluidizing unit 708 and the supporting structure and moveable platen 714, can be positioned directly under the cyclone outlet, particularly if a single cyclone is used. This configuration allows the supply 22 to be exhausted through the cyclone to the after filter, rather than using the additional duct work described in the exemplary embodiment herein above. In most cases, this configuration would utilize a vortice breaker between the cyclone and the supply 22 so as to minimize adverse affects, if any, of the cyclone operation on the fluidization and suction functions of the supply 22. Operation of the supply 22 would be substantially the same as the exemplary embodiment herein.

[Para 235] The invention has been described with reference to the preferred embodiment. Modifications and alterations will occur to others upon a reading and understanding of this specification and drawings. The invention is intended to include all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.